Next Meeting, Chemists' Club, New York, October 28, 1904.

Subject: Transmission of Intelligence.

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TRANSACTIONS

OF THE

AMERICAN INSTITUTE

OF

ELECTRICAL ENGINEERS.

CONTENTS.

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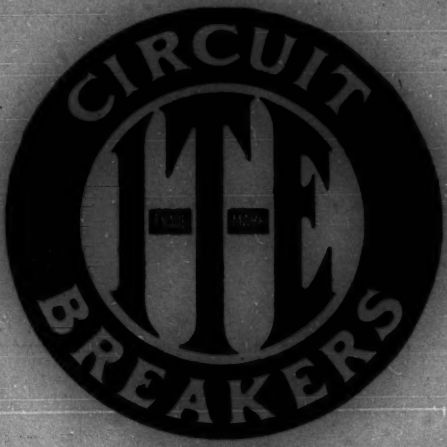

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TRANSACTIONS

OF THE

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Vol. XXI. OCTOBER, 1904. No. 8

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SECTION I.

GENERAL INSTITUTE MATTERS.

This section contains INSTITUTE matters of general interest formerly printed in the Monthly Announcement. Being of a temporary nature these items will not be printed in the bound volumes. In future the bound volumes will contain only matters that are intended for permanent record—reports of committees, technical papers, discussions on these papers, and written communications relating to them.

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NEXT MEETING, OCTOBER 28, 1904.

TRANSMISSION OF INTELLIGENCE.

1. *The Telautograph*, by JAMES DIXON, Associate; Electrical Engineer, Gray National Telautograph Company, New York.

2. *The Transposition of Electrical Conductors*, by F. F. FOWLE, Associate; Railway Department, American Telephone and Telegraph Company, New York.

PLACE OF MEETING.

CHEMISTS' CLUB,
108 West 55th St., New York.

FUTURE MEETINGS.

November 25,

HEAVY ELECTRIC TRACTION.

December 23,

CENTRAL STATIONS.

January 27, 1905,

TRANSMISSION PROBLEMS.

APPLICATIONS FOR ELECTION.

Applications have been received by the Secretary from the following candidates for election to the INSTITUTE as Associates, and will be considered by the Board of Directors at a future meeting.

Any Member or Associate objecting to the election of any of these candidates should so inform the Secretary before November 25, 1904.

4108 R. P. Moses,	Taylor, Cal.
4109 Ernest A. Wolfe,	Philipsburg, Pa.
4110 Albert M. Allen,	Weehawken, N. J.
4111 Elliott M. Sergeant,	Boonton, N. J.
4112 Ralph G. Hussey,	Newport, R. I.
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4117 Arthur StC. Dunstan,	Auburn, Ala.

4118	Warren Partridge,	Orange, N. J.
4119	George R. Alexander,	Sacramento, Cal.
4120	Edward W. Stone,	Asheville, N. C.
4121	Henry H. Carter,	Barbadoes, B. W. I.
4122	Jorge Newbery,	Buenos Aires, A. R.
4123	William E. Skinner,	Winnipeg, Manitoba
4124	Gerhard M. W. Goettling,	Boston, Mass.
4125	John T. Cowlin,	Mt. Vernon, N. Y.
4126	Warren B. Sanford,	New York City.
4127	Herbert A. Clarke,	Philadelphia, Pa.
4128	Alan E. Flowers,	Columbia, Mo.
4129	Francis S. Denneen,	Brooklyn, N. Y.
4130	Wilfred A. Daly,	Wilkinsburg, Pa.
4131	Charles J. Russell,	Philadelphia, Pa.
4132	J. A. Renstrom,	Hidalgo, Mexico.
4133	Charles E. Robertson,	Buffalo, N. Y.
4134	Felix Levy,	New York City.
4135	Maxwell R. Berry,	Connellesville, Pa.
4136	Lucien Hill,	Connellsville, Pa.
4137	R. Homer Wood,	Richmond, Va.
4138	Henry R. Snyder,	St. Louis, Mo.
4139	Hartley LeH. Smith,	Brooklyn, N. Y.
4140	Luther L. Emerson,	Pittsburg, Pa.
4141	Leopold G. E. Morse,	London, Eng.
4142	Thomas B. Lambert,	Chicago, Ill.
4143	William W. Harris, Jr.,	St. Louis, Mo.
4144	Ira G. Walborn,	Provo, Utah.
4145	Siegfried G. Freund,	New York City.
4146	David K. Morris,	Birmingham, Eng.
4147	Tom P. Strickland,	Sydney, N. S. W.
4148	Theodore I. Jones,	Newark, N. J.
4149	Louis R. Gaiennie,	St. Louis, Mo.
4150	Wilfrid N. Kernot,	Melbourne, Aus.
4151	Arthur C. F. Webb,	Sydney, N. S. W.
4152	Robert Hammond,	Manchester, Eng.
4153	William H. Reynolds,	New York City.
4154	Axel F. Enstrom,	Stockholm, Sweden.
4155	Thomas Hesketh,	Folkestone, Eng.
4156	Theodore J. V. Feilden,	London, Eng.
4156	Llewelyn Owen,	Peoria, Ill.
4158	Joseph L. Gensler,	New York City.
4159	Hans J. Meyer,	Shreveport, La.

4160 William G. T. Pope, Lisbon, Portugal.
4161 L. Frank Kohler, New York City.
Total, 54.

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HARRY PARKER GIBBS, Chief Engineer to government of Mysore, Bangalore, India.

DOUGLASS BURNETT, General Manager, United Electric Light and Power Co., Baltimore, Md.

BRANCHES AND STUDENT MEETINGS.

It is expected that the Branches and Student Meetings of the INSTITUTE will organize and begin the year's work during the present month. The Chairman of the Committee on Local Organization has sent a letter to the Local Secretaries which is reproduced below. In this letter reference is made to a report of the Committee of the last year which was made to the INSTITUTE at the May meeting. This report has been printed in the May, 1904, issue of the monthly TRANSACTIONS. In this report reference is made to replies to a letter of inquiry which were received from various Branches. Extracts from these replies were incorporated in the report. Two of these reports are printed at this time, as they show the various phases of Branch and Student work, and as they contain fruitful suggestions with regard to the conduct of the work under the circumstances which prevail in each case.

The Chicago Branch was the first one founded. The report from Cornell University indicates in a clear manner the relationship between the college student and the INSTITUTE.

LETTER FROM CHAIRMAN OF LOCAL ORGANIZATION COMMITTEE, SEPT. 27, 1904.

To the Secretaries of Branches,
American Institute of Electrical Engineers.

GENTLEMEN: President Lieb has requested me to serve as Chairman of the Committee on Local Organization during the coming year. It is important that the branch work be taken up in due season and that it be undertaken with earnestness and activity.

It may be well at the beginning of the year to consider the objects to be obtained and the ways and means of effecting

procedure. I commend for your consideration the report on Local Organizations made to the annual meeting of the INSTITUTE last May, which has already appeared in the TRANSACTIONS. The quotations from the reports sent in by various branches are fruitful in suggestion and inspiration.

Your particular attention is called to the By-Laws recently adopted by the Board of Directors pertaining to Branch meetings. It is expected that the Branches will organize and that the work of the present year will be conducted in conformity with the By-Laws. Local meetings in universities and technical schools where there are only a few INSTITUTE members cannot be ranked as Branch meetings, but will be classed as Student meetings.

The first New York meeting of the INSTITUTE will not be held until the 28th of October. If the branches await the proceedings of this meeting before organizing much time will be lost. It is suggested therefore that meetings be held in October for the organization of the year's work and, when found desirable, for general discussion of the methods of conducting the work through the year. As a subject for this meeting a selection may be made from the material presented at the High-Tension meeting held in Chicago in June. The papers have already appeared in the TRANSACTIONS sent to the members. The answers to questions relating to high-tension transmission and the discussion of several of the papers have just been sent out in the September TRANSACTIONS. The rest of the discussions will be printed in the October TRANSACTIONS. It will be best to make a definite selection of one or two of the papers or of a few topics from the answers to questions with a view to securing those subjects which may be most profitable to your meeting.

In accordance with Section 54 of the By-Laws please make an estimate of the proposed expenses chargeable to the INSTITUTE from November 1, 1904, to October 31, 1905. The estimates should be sent to Secretary Pope before October 20 in order that the matter may receive the prompt consideration of the Finance Committee and the Board. The INSTITUTE has no special fund for the support of Branches, no appropriations are made of money to be spent, although the INSTITUTE has been willing in the past to meet certain reasonable meeting expenses.

INSTITUTE meetings are held regularly in eight of the ten

cities visited by the "circular tour" of the INSTITUTE and its foreign guests during the past month. Our Branches were very active and helpful in receiving their guests.

One of the prime advantages of local organization is that it enlarges by many fold the number of members who are brought into direct personal contact with INSTITUTE organization and meetings. More than this, the electrical profession as it stands to-day is the result of a rapid growth covering only a few years. INSTITUTE Branches constitute one of the best means for unifying this rapidly growing profession and for receiving and assimilating the young men who are entering it and upon whom the work of the next ten or twenty years will devolve. The conditions which confront us are different from those in any of our sister professions; they require new methods if the INSTITUTE is to meet fully the opportunity which lies before it, and the INSTITUTE looks to its Branches as a most effective means of promoting the interests of the INSTITUTE and of the electrical industry, as well as of the individual.

Very truly yours,

(Signed) CHAS. F. SCOTT,

Chairman Local Organization Committee.

REPORT FROM CHICAGO BRANCH.

CHICAGO, May 9, 1904.

CHAS. F. SCOTT, *Chairman,*

Committee on Local Organization.

DEAR SIR: We have had a very successful series of Branch meetings in Chicago this winter.

As chairman of the Local Committee, I have been interested in studying our work here, and as I analyze it, our success is due to the following causes:

First: We have aimed to have a few good meetings rather than a larger number of comparatively poor ones.

Second: The program for each meeting has been carefully prepared. This has been done by concentrating the responsibility for the evening by appointing one member of the local committee in charge of each program. This chairman makes an effort to secure discussions upon the INSTITUTE papers from various local members who are prepared to furnish competent discussion. At least six discussions of this kind have been secured for each meeting. These discussions are called for as parts of the program, so that the meetings have gone off with a vim.

Third: We have recently emphasized the social features of the meeting by encouraging the members to meet together for dinner. By having this dinner promptly at 6.30, quite a delegation arrives at the meeting place by 7.30, allowing for a half hour of very pleasant social intercourse. This feature has been so successful that we hope to make it a permanent one.

Fourth: The Local Committee are representative of the various branches of the industry, and have taken a genuine pleasure in their work, usually meeting at a round table for luncheon to discuss their plans. The "esprit de corps" of the committee has naturally spread to the local members.

Fifth: A more general interest in the selection of officers of the National Body has lately been noticeable and the selection of a number of local members for important committees has had a beneficial effect in strengthening the local feeling.

Sixth: Personally, I believe the best interests of the Local Branch of the INSTITUTE in general is conserved by following the general INSTITUTE programs, rather than encouraging the production of strictly local papers. This will leave matters of purely local electrical interest to be handled by the newly formed "Electrical Section of the Western Society of Engineers," thus securing for both organizations the support which they deserve.

My answer to your questions briefly as follows:

First: The Branch Meetings increase the value of the INSTITUTE to members of the local branch at least 100%.

Second: To increase personal interest in any organization is best accomplished by giving each member something definite to do. This can best be done by a local organization.

Third: Fully two thirds of the attendance at our local meetings have been young men who have not yet become members of the INSTITUTE. It is hard to say how any better plan than that of local meetings could be adopted to educate future members to the possibilities of the INSTITUTE work.

Fourth: One of the great values of the student meetings is that it brings in to the colleges a genuine atmosphere of affairs, which is very desirable in increasing the acquaintance of the student members with men who do things, and with the problems which they solve.

Fifth: I believe that the Branch work in Chicago has doubled the efficiency of the general INSTITUTE work as far as our local membership is concerned.

Sixth: There is not only a constant interest in our Chicago Branch work, but our success for the past two years leads us to expect very much from next year's work. The interest is growing steadily and surely. There certainly would be a very decided objection if the Branch work were to be discontinued, and the prospects for the future are very encouraging.

Trusting that this will cover your inquiry, and regretting that the answer has been so long delayed, I am,

Yours very truly,
(Signed) G. A. DAMON,
Chairman Local Committee.

REPORT FROM CORNELL UNIVERSITY.

ITHACA, N. Y., May 7, 1904.

MR. CHARLES F. SCOTT,
Chairman Committee on Local Organization.

DEAR SIR: Regarding the conduct of the Cornell Branch of the INSTITUTE during the present year, kindly permit me to make to you the following report: First of all I want to express to you our pleasure in receiving the copy of statistics relating to the INSTITUTE branches. The data therein contained are very helpful and suggestive in a number of ways. For example, we are surprised that only one third of our young men who have attended the meetings and received copies of the papers and similar INSTITUTE benefits have become A. I. E. E. students and paid the corresponding fees. We have heretofore kept no account of these numbers and let the matter take care of itself after presenting to our young men at our opening meeting the advantages of becoming INSTITUTE students, when we distributed the application forms. We are satisfied that many more of our young men would gladly have become A. I. E. E students had we referred to the matter later on and brought to their attention the importance of their making a better return for the benefits received.

We are not able to say just how much the membership has been increased on account of the influences of our Branch. We believe, however, that the young men go from the University after graduation with a comprehensive understanding of the great value of the INSTITUTE transactions, the importance of becoming an associate member at the earliest practicable date and coupled with a worthy desire to make ultimately so satisfactory a professional record that they may become members.

I believe such an influence must ultimately be responsible for a very material increase in membership due to our Branch. The circumstances in relation to the University and the locality are such as to cause the main, almost the only object of our Branch, to secure to the student the benefit to be derived from contact with the INSTITUTE chiefly through its transactions. During the past ten years there has existed among our students a vigorous organization known as the Cornell Electrical Society. This society holds usually about 15 meetings a year for the purpose of hearing lectures or engaging in discussions. These lectures have been given by our officers of instruction and the discussions have been conducted by the students, *i.e.* the members of the society. The lectures have always dealt with the scientific progress of electrical applications and accounts of their physical, electro-chemical and engineering investigations that have been in progress during the current university year. These lectures usually occupy the first half of the year and the papers and discussions by the members of the society, *i.e.*, by the students themselves, take up the latter half of the year with subject matter relating almost wholly to their thesis work. This society publishes for the benefit of its members each year abstracts of all the lectures and papers.

I know you must appreciate the great benefit to our students that comes to them because of this society. The success of the Cornell Electrical Society in bringing social and technical benefits to our students induced our mechanical engineering students some five years ago to organize a similar society with a membership from junior and senior classes in mechanical engineering courses. Every bit of the conduct of these societies is in the hands of the students, the officers of instruction helping them only by accepting upon occasion places upon their programs. On May 2, I attended their first annual banquet, a joint social effort on the part of these two societies. I was greatly pleased at the progress these young men have made in public speaking through their experience in the work of their societies as shown by what they had to say in response to calls from their toastmaster.

I have made this digression for the purpose of showing you why we have not established the work of our Branch through a student organization similar to that of our Electrical Society. In analyzing this matter we found that there was a place for both, that is, the results accomplished by the electrical society

and those accomplished by the INSTITUTE Branch. This is one great reason why we have in the past held most of our Branch meetings at an hour that would otherwise be given up to regularly required work for our seniors in electrical engineering. Another reason for doing this is that we want to require that every one of our electrical engineering graduates shall possess knowledge of the INSTITUTE, the benefits to be derived therefrom, to have a start in the study and understanding of the transactions, and finally to know something of the men who have been or who are now prominent in its management or in the contribution to its transactions. We have remodeled the schedule of our senior courses somewhat for the express purpose of devoting one hour of required work per week to the INSTITUTE and its transactions. Heretofore, our schedule has not permitted us to do this and we have not in consequence been able to have so many meetings devoted to the INSTITUTE as our policy has determined. The schedule which will go into effect next year will enable us to hold from 30 to 35 one-hour meetings in which we can accomplish all of the results in the year in regard to the INSTITUTE and its transactions that our policy contemplates.

Very truly yours,

(Signed) HARRIS J. RYAN.

SECTION II.

PAPERS AND DISCUSSIONS.

This section contains INSTITUTE matters of a permanent nature; these matters will be eventually reproduced in the bound volume compiled at the end of the calendar year.

A paper to be presented at the 190th Meeting of the American Institute of Electrical Engineers, New York, Oct. 28, 1904.

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THE TELAUTOGRAPH.

BY JAMES DIXON.

Electrical transmission of handwriting has engaged a certain amount of attention ever since telegraphic transmission of printed characters was successfully carried out.

As early as 1886 Cowper and Robertson brought the writing telegraph[1] into a fairly operative form. This instrument was adapted to operate several receivers in series in "reporting" service, where the regular news ticker service was unobtainable or too expensive. The system was put to some use, chiefly in Pittsburg and vicinity.

The writing was received on a paper tape, advanced at constant speed by clockwork. No pen-lifting device was provided and the words were connected together by a mark of the pen, making figure work poor. As the characters were formed by the combination of the pen motion and the tape motion, a certain amount of practice and skill was required to produce a legible message.

The electrical features were as follows: two independent variable currents were obtained from the transmitter; these passed over lines to the receiver where they traversed two electromagnets set at right angles to each other, and so influenced their effect upon a common armature as to cause the receiver-pen rod to reproduce the motion of the transmitter pencil.

It will be noted that this principle is nearly identical with that of Grühu's Telechipograph,[2] recently described in the technical press, the main differences being that the telechipograph

1. Wm. Maver, Jr., *American Telegraphy*.
2. *Scientific American*, August, 1903.

writes upon a larger field and uses a beam of light, and photographic record instead of a pen with ink record.

Following the writing telegraph, Professor Elisha Gray constructed, at his Chicago laboratory, an instrument which wrote upon stationary paper, and which he called a telautograph. It required four line wires and operated as follows: by means of cords and drums the motions of the transmitting stylus were resolved into two component rotary motions which were used to operate two mechanical interrupters in the primary circuits of two induction coils. The relations of the parts were such that a motion of the transmitting stylus amounting to one-fortieth of an inch caused a complete make-and-break at one or both of the interrupters.

The line currents were the impulses produced in the secondary circuits of the induction coils. These impulses passed over lines to two electromechanical escapements in the receiver. By means of cords and drums their motions were combined and caused to act upon the receiver pen. By the use of relays and condensers and a local battery at each receiver, the paper was advanced when necessary and the pen lifted from and lowered to the paper. The mechanical difficulties met with in perfecting this instrument were very great, and in the apparatus exhibited at the World's Fair in Chicago in 1893 the escapement mechanism was brought to a perfection thought impossible of attainment only a short time before. The writing showed a saw-tooth or step-by-step character due to the action of the escapements. The instrument was abandoned on account of the number of line wires required, limited speed, numerous fine adjustments, and cost and difficulty of manufacture.

In 1893, while still working at the escapement device, Professor Gray patented a variable-current instrument,[1] using two line wires, which worked, in a general way, like the present telautograph. The motions of the transmitter pencil were resolved into two components which were used to vary two line currents, the variable resistances being carbon rods dipping into tubes of mercury. The receiver contained two D'Arsonval movements, to the moving elements of which the pen-arms were attached. Professor Gray never developed this instrument much beyond the laboratory stage, probably on account of his firm belief in the escapement type.

Foster Ritchie, at that time an assistant to Professor Gray,

1. U. S. patent 494,962, April 4, 1903.

gave considerable attention to this patent and perfected an instrument based on it. He obtained a patent for improvements[1] and has produced an instrument that operates in a fairly satisfactory manner[2] under certain favorable conditions.

The telautograph has been brought to its present state chiefly through experimental work done by, or under the personal direction of, Mr. George L. Tiffany, to whom several patents[3] for improvements have been granted. Mr. Tiffany's instrument operates upon the variable-current principle and includes a number of interesting features, among them what may be called a straight-line D'Arsonval movement, which is used to operate the receiver.

The operation may be briefly described thus: at the transmitter a pencil is attached by rods to two lever-arms which carry contact-rollers at their ends. These rollers bear against the surfaces of two current-carrying rheostats, connected to a constant-pressure source of direct current. The writing currents pass from the rheostats to the rollers and from them to the line wires. When the pencil is moved, as in writing, the positions of the rollers upon the rheostats are changed and currents of varying strength go out upon the line wires. At the receiver these currents pass through two vertically movable coils, suspended by springs in magnetic fields, and the coils move up or down according to the strengths of the line currents. The motions of the coils are communicated to levers similar to those at the transmitter, and on these levers is mounted the receiver pen, which, by the motions of the coils, is caused to duplicate the motions of the sending pencil. Fig. 1 shows the circuits of the instrument.

Many of the principles and devices in the instruments are of considerable interest. The method by which the variable currents are obtained is the laboratory arrangement for securing a variable pressure from a direct-current, constant pressure circuit; that is, the line circuit (of constant resistance) is connected as a shunt around that part of the rheostat between the moving roller and the ground or return. Motion of the roller varies the amount of resistance in series with the line and also the amount in parallel with it and fine gradations are easily obtained, giving smooth motion of the receiver pen. In this

1. U. S. Pat. 656,828, Aug. 28, 1900.
2. *Elec. World and Engineer*, Dec. 8, 1900, Vol. XXXVI., No. 23.
3. U. S. patents 668,889 to 668,895 inclusive, Feb. 26, 1901.

way a variable pressure is impressed on the line circuit, giving a variable current. In all the other variable-current instruments, a constant pressure was impressed on line and a resistance in series with the line varied to give the desired variations in current. One result of the shunting method is a better form of rheostat, more easy of construction and handling, in which, also, the heating is better distributed.

The rheostats are wound upon castings of I cross-section, with the turns of wire lying close together on the inner or contact-face. After winding, the insulation on this face is saturated with glue, which is allowed to harden and is then

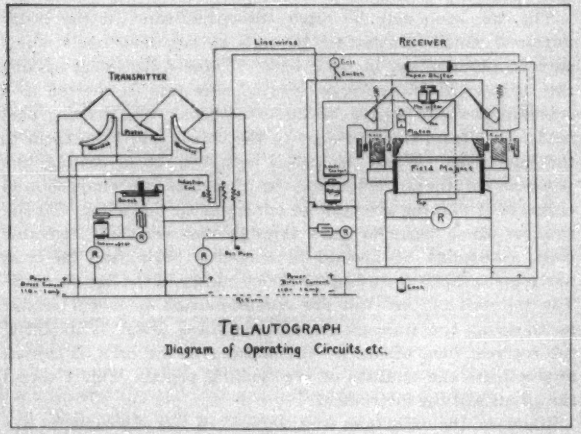

FIG. 1.

scraped off, taking the insulation with it, and giving a surface where contact is possible on every turn of the wire. This gives a rheostat of a large number of small steps, of good mechanical construction, and of low cost.

The receiver operates with what may be called a straight-line d'Arsonval movement. The moving element or coil is wound upon a copper shell for damping effect. The magnetic circuit is so arranged that one pole surrounds the other, forming an annular air-gap of short length and large cross-section in which the direction of the flux is radial. The field is electro-

magnetic and is highly excited, to secure uniformity. The coil, suspended in the annular space, moves up or down with little friction, as it touches the sides of the space of the core very lightly if at all. The principle is the well-known one that a current-carrying coil, in a magnetic field, tends to place itself with respect to the field so that the flux enclosed by the coil shall be a maximum.

The current for operating is taken from the ordinary lighting mains, preferably at about 115 volts. Satisfactory operation has resulted with pressures from 80 up to 250. At 115 volts, receiver and transmitter each require about one ampere while in operation. Fairly steady pressure is necessary as the receiver, being in effect a voltmeter, is rather sensitive to sudden changes, the effect being slight distortion of the message.

A master-switch at the transmitter is provided to do all necessary switching of line and power circuits, to make needed changes in connections and to cut off current when not writing. A relay in one of the lines closes the power circuit of the receiver whenever the transmitter at the distant station is switched on, and serves to prevent waste of current when not in operation.

Attached to the master-switch is a mechanical device which shifts the transmitter paper the space of one line of ordinary writing for each stroke of the switch. The relay mentioned controls the electrical receiver paper shifter and, as each stroke of the switch causes a stroke of the relay, the receiver paper is shifted an amount equal to that at the transmitter. The writing space is about two inches long and five inches wide, allowing for three or four lines of writing. When filled by messages a few strokes of the switch serve to bring fresh paper into position at both receiver and transmitter.

To prevent switching on of the transmitter while its home receiver is receiving a message from the distant station, an electromagnetic lock is connected in the receiver power circuit, controlled by the relay, and locks the home transmitter in the "off" position until the distant transmitter is switched off. If both transmitters were switched on at once neither station would receive any message; the lock is provided to render this condition impossible.

The ink supply is most important and is arranged for as follows: at the left of the receiver platen is a bottle with a hole in the front near the bottom. When filled with ink and tightly corked the ink does not run out of this hole because

of the pressure of the atmosphere. The ink is accessible for the pen at the hole and the surface of ink exposed to evaporation is small.

The pen is made of a piece of german silver bent double, after the manner of a ruling pen, and makes a uniform line in any direction over the paper. It takes up its supply by capillary attraction, from the hole in the front of the bottle. When the receiver is switched off, retractile springs draw the pen-arms to stops so arranged as to bring the pen exactly in front of the hole in the bottle, and when the pen-lifter armature is released the pen is caused to insert its tip in the opening. Thus a fresh filling of ink is obtained each time the paper is shifted. When not in use the pen rests in the ink, always ready to write.

For the prevention of mechanical shocks to the necessarily light moving system of the receiver, it has been necessary to supply means to prevent the switching on or off of the transmitter, and by that action of the receiver, when the transmitter pencil is "out in the field"; that is, at a position other than that corresponding to the opening in the receiver ink-bottle; as in that case the receiver pen would instantly jump to a similar position. This position is called the "unison point," a term having its origin in the days of the "self-propellor" escapement telautograph. By placing a catch, released at only by pressure of the pencil-point upon it, at the transmitter unison point the desired result is accomplished and the transmitter master-switch can not be switched either "off" or "on" unless the pencil be placed at the unison point and held there until the stroke of the switch is completed. In this case, as everywhere, the apparatus is made strong enough to stand any possible shocks, and then every precaution is taken to prevent their occurrence. Aside from shock to the moving system these jumps might shake the ink supply out of the pen and prevent the recording of the message.

The pen-lifter is a magnet placed back of the receiver writing platen, and carrying upon its armature a rod adapted to engage with the pen-arm rods and raise the pen clear of the paper when the magnet is energized. This magnet is controlled from the transmitter as follows: beneath the transmitter platen is a spring-contact, opened by pressure of the pencil upon the paper, and closed by a spring when the pencil is raised. An induction coil having an interrupter in its primary circuit is so

connected to this spring-contact that when the pencil is raised the primary winding is short circuited. The induction coil has two independent secondary windings through which the two variable line currents pass before leaving the transmitter. The effect of the induction coil and its interrupted primary current is to induce in the two line currents superimposed vibrations or "ripples" when the pencil is pressed down on the paper and the spring-contact is open. When the contact is closed, by its spring, and the primary winding is cut out, no vibrations are produced in the line currents. In one of the line wires, at the receiver, is placed a relay upon whose sheet-iron diaphragm armature is mounted a loose contact, consisting of two platinum-silver contacts in series, sealed in a glass tube, to prevent oxidation. A local circuit contains the winding of the pen-lifter magnet and this loose contact.

When the vibrations are present in the line current, due to the pressure of the pencil upon the paper and consequent opening of short circuit of the primary of the induction coil, the diaphragm of the relay is shaken, the loose contact opened and the pen-lifter de-energized, its armature is drawn back by a spring and the pen is allowed to rest against the paper. When there are no vibrations in the line currents due to the raising of the pencil from the paper, the relay diaphragm is at rest and the pen-lifter is energized and the pen is lifted clear of the paper.

The superimposed vibrations used for operating the pen-lifter have another minor effect. The suspended coils, and through them the entire moving system of the receiver, are kept in a state of very slight mechanical vibration while the pen is on the paper. This aids the flow of ink from the pen-point, assists the pen in passing over any roughness or irregularity in the surface of the paper, and materially reduces friction in the joints and pivots of the moving system, and results in better writing. In some of the later instruments the two relays, that for pen-lifting and that for paper-shifting and power switching, are combined in a single piece of apparatus.

For signalling, a push-button is placed upon the transmitter and a call-bell or buzzer is mounted on the receiver. This circuit is disconnected by the master-switch while a message is being written. Spring reels are attached when needed to roll up the received messages for preservation and future reference.

The ordinary arrangements for operation are as follows: the instruments may be operated singly, upon a private line

having an instrument at each end, or on an exchange system where a switchboard provides for connection. Working in this way, satisfactory writing has been obtained with a resistance in each line wire of 1600 ohms and an operating pressure of 110. Multiple operation can be carried out to a limited extent, three receivers being at present the maximum number that can be operated at once, in multiple, using 110 volts. This allows of placing a supervisory machine upon a line.

When no response to messages beyond a bell signal, is required, and the same message is to be sent to a number of stations, a series arrangement of receivers is used. With a transmitting pressure of 110 volts a maximum of seven receivers can be operated from a single pair of transmitting rheostats and rollers. This number may be increased by increasing the pressure or by adding additional rheostats and rollers, operated by the same pencil. Using both these methods a maximum of 50 or more receivers may be operated at once.

Instances in actual commercial use of the arrangements of instruments mentioned are: private lines; the transmission of mail and other orders from office to factory or yards; investigation of checks over lines between paying tellers and bookkeepers in banking concerns, and transmission of messages, usually in cipher, between brokerage firms and cable or telegraph offices. A few moments' thought will bring to mind many places where a telautograph private line could be used to save time and trouble, especially where accurate transmission of figures is essential.

Multiple operation may be resorted to when a third station upon a line desires a record accessible at any time, of what is being sent, as, for instance, when one of the officers of a bank desires to know what passes between his bookkeepers and paying tellers. On such a line the third station receives all messages and can write to either or both of the other stations, should the necessity arise.

Series operation may be used when several stations are to receive the same message and no response except a bell signal is required, as in sending orders in a hotel or club from dining room to kitchen, pantry and wine room; in "reporting" or news service, or for bulletin work, such as the announcement of arrival and departure of trains to a number of stations in a large railway station or freight depot. Fig. 2 shows the standard commercial instrument.

One of the most important uses for series systems has been found in the U. S. Coast Defence Service, in sending ballistic data, such as range and azimuth of target, or character of projectile, from position-finding stations to the gunners. This is called " fire-control communication " and is installed in the forts by the U. S. Signal Corps. In a paper presented by Col. Samuel Reber on " Electricity in the Signal Corps,"[1] will be found a description of the position-finding systems and the desired characteristics of a system of communication for sending this data to the guns are stated as follows: " The system that will successfully solve this problem must be simple in construction, mechanically strong so as not to be affected by the

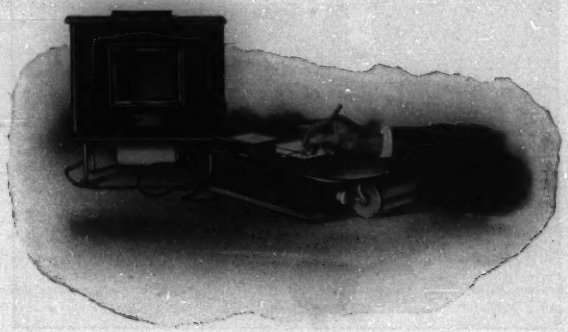

FIG. 2.

blast, as the receivers are placed close to the guns, rapid in operation, and give a character of record that can be read without liability of error." Since that paper was prepared it has been decided that the receivers must be mounted directly on the gun-carriage and can have no shelter other than that afforded by their own cases. Add to these requirements the facts that the instruments must be cared for by post electricians, and operated by enlisted artillerymen, messages must be visible at night; and the operation must be independent of rain, salt mists, cold, heat, or tropical insects, and it is apparent that no easy problem is presented.

A special type of telautograph has been designed for this

1. TRANSACTIONS, A. I. E. E., Vol. XIX., pp. 723 and 724.

service and has been adopted by the U. S. Signal Corps[1] for fire-control communication.

In this service " telautograph " the rather delicate pen-lifter relay is eliminated and the receiver pen-lifters are operated over a third line wire by the transmitter platen switch directly.

Each gun receiver is enclosed in a water-tight brass case, suspended by springs from the gun carriage directly in front of the gunner. The parts are as far as possible made " brutally strong," and the construction is as simple as possible.

The desired rapidity of operation is inherent to the telautograph, and accuracy of record is ensured by careful writing and

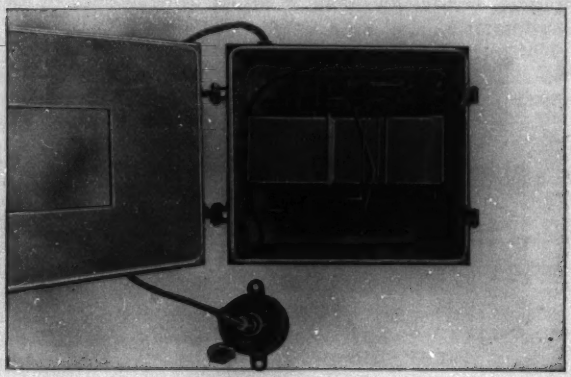

FIG. 3.

by the use of a " home " receiver, mounted at the transmitter, where the operator can see it plainly, which is connected in series with the gun receivers and records the messages as actually sent over the line.

Freezing of ink is prevented by the addition of alcohol; and rain, mists, and insects, as well as the effects of the blast, are shut out by the metal case. A heavy glass window is placed in the case so that messages can be read without opening the case.

A small incandescent lamp inside the case lights automatically when the receiver is writing and may be lighted by pressing a

1. TRANSACTIONS, A. I. E. E., Vol. XIX., p. 673.

button at other times, thus providing for visibility at night. Fig. 3 shows the army type of receiver mounting.

On warships there is a somewhat similar service to be rendered and the performance of this should fall to the army type of telautograph.

Commercial service has given opportunity for the installation of a considerable number of private line telautographs in actual use, and at least three of each of the other typical installations are in operation at the present time.

Much of the improvement in details of construction and reliability in operation has resulted from experience gained in efforts to perfect the service of these commercial plants. The experience leading up to the special army type of telautograph has extended over a period of about five years and in the present instrument all the requirements, unusually severe as they are, have been successfully fulfilled.

A paper presented at the 189th Meeting of the American Institute of Electrical Engineers, St. Louis, Mo., Sept. 14, 1904.

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PRESIDENT'S ADDRESS.

BY BION J. ARNOLD.

Eleven years ago this summer it was our privilege to meet under the auspices of a great Exposition, located upon the shores of Lake Michigan, organized not only to commemorate the 400th anniversary of the discovery of this country, but also to direct attention to the advancement made in the various fields of the world's activities, and especially in those arts in which we, as workers, were most interested.

To-day we meet under the auspices of another great Exposition, brought into being to commemorate the 100th anniversary of the peaceful acquirement by the Government of the United States of a large portion of the territory now contained within its borders, to have our attention directed to the development of the various industries of this and other countries that have taken place during the intervening years.

For a few years preceding the former Exposition, engineers and other engaged in electrical pursuits had had their energies absorbed in attempting to show the owners of street railways that operation by electricity was cheaper and better than by means of the horse or the cable. We, at that time, had seen the horse practically disappear from street railway service and the cable supplanted in some instances.

The more ambitious engineers were then advocating the use of electricity on elevated railways, and making figures to prove to the owners of such railways that electricity was cheaper in operation and more desirable for such conditions than steam locomotives, then universally used for such work.

At that Exposition was placed in operation an elevated electric road, known as the Columbian Intramural Railway, which though the Central London Underground, a road of light equipment, was started some time before, and the Liverpool Overhead Road soon after, was the first practical commercial application

on a large scale of electricity for the propulsion of heavy railway trains. The success of these roads gave the electric railway industry an impetus which has since resulted in the abandonment of steam and the adoption of electricity on every elevated railway now in operation, and practically on all of the underground roads, thus effectually proving the soundness of the theories of those engineers who pinned their faith to the correctness of the conclusions which their figures showed, and who staked their reputations upon the future to prove them true.

The interval between these Expositions has also been one of great activity and development in the field of interurban railways, which has brought into being the extensive use of the alternating current, rotary converter sub-station system of operating direct-current roads, resulting in the interlinking of thousands of cities with each other and intervening points, thus not only affording a new field for the investment of capital but bringing to most of the inhabitants of the territory through which these roads pass greater facilities for the prosecution of business and the widening of their social life.

With the introduction of the suburban railway came an increased volume of passenger travel, induced by the increased facilities, which may well be noted by the managers of great steam railway properties as an example of what may be expected in increased revenue when frequent and pleasant service is available to the public.

The energies of those engaged in electrical industries have thus far been absorbed in fields which now seem to have been naturally theirs, and their success has been such that they now aspire to enter the field occupied by the steam locomotive as a legitimate field of conquest.

The question now is whether this field is one in which the advantages of electricity will be sufficient to overcome the obstacles which seem almost unsurmountable, and enable it to win as it has in the cases cited.

Those who have given the subject little thought or who are unable to analyze it carefully on account of the lack of the technical knowledge necessary to apreciate the difficulties to be overcome, are most apt to predict the early supremacy of the electrically driven train over the steam locomotive.

That the fields referred to have been apparently formidable yet quickly overcome is not necessarily proof, or even good evidence, that the legitimate field of the steam locomotive can be entered and successfully achieved.

Those most familiar with the subject are now prepared to admit that our great steam railway terminals, where many switching locomotives are shunting back and forth continuously, and those portions of the steam roads entering our great cities, where suburban trains are numerous, frequent and comparatively light, can be more economically operated by electricity than by steam. This is evident to most of those engaged in the work, for the reason that it simply means duplicating, on a large scale, the systems which have proven successful in our street railways, operating, as they do, numerous units running at frequent intervals.

Proof that this field is recognized as a legitimate one for electricity is furnished in the examples of steam railway terminals that are now being equipped electrically, such as the lines of the New York Central and Pennsylvania Railroad Companies in the vicinity of New York, involving an expenditure of something over $70,000,000, where not only suburban service will be operated electrically, but where in the case of the New York Central, the main line trains will be brought into the city from points 30 to 40 miles distant.

While these are great examples of electrical operation on steam railroads, and heroic instances of faith on the part of the railway managers in the ability of electricity to successfully meet the conditions of steam railroad work, where the trains are sufficiently frequent, they are by no means conclusive evidence that electrically propelled trains can be made to successfully meet the conditions of trunk line passengers and freight service, the field now so successfully held by the steam locomotive.

The best conditions for electrical success are a great number of units moving at a practically uniform schedule, at equal intervals, within a limited distance.

The legitimate field of the steam locomotive is now one in which there are few but heavy units moving at uneven speeds over long distances at unequal intervals and at high maximum speeds.

The amount of energy transmitted to any great distance and used by electric cars that have been put in use until recently has been small when compared with the amount of energy that it takes to propel a steam railroad train of five or six hundred tons weight at the speeds ordinarily made by such trains.

It may be taken as axiomatic that when investment is taken

into consideration, power cannot be produced in a steam central station, under conditions that exist to-day, and transmitted any great distance to a single electrically propelled train, requiring from 1000 to 2000 h.p. to keep it in motion, as cheaply as a steam locomotive, hitched directly in front of the train will produce the power necessary for its propulsion. Therefore, there must be other reasons than the expected economy in power production to warrant the adoption of electricity on a trunk line railway unless it can be shown that the trains are frequent enough to make the saving in the cost of producing power greater than the increased fixed charges made necessary by the increased investment due to the adoption of electricity.

There are undoubtedly in existence to-day conditions where water power in abundance is available along the right of way of existing roads, in which the substitution of electricity for steam could be made a paying one, with apparatus now available, even on roads having a comparatively infrequent service, but these are special cases and only tend to prove the correctness of the position, for in these special cases the cost of power would be but little over half the present cost of producing it by means of a central steam-driven station.

The ideal conditions for any trunk line railroad having a traffic heavy enough to warrant the investment in a sufficient number of tracks to properly handle this traffic in such a manner as to get the most efficient service out of its rolling stock, would be to have four or more tracks between terminal points, upon which, in pairs, could be run the different classes of service at uniform rates of speed. Thus, if six tracks were used, the through line, passenger, and express service would be run on one pair of tracks; the local passenger, local express, and local freight service upon another pair of tracks; while the through freight service would be run upon a third pair of tracks, and all the trains upon any pair of tracks would run at the same average speed and stop practically at the same places.

If these conditions could prevail and the traffic were sufficient to warrant this investment in tracks, such a service could be operated more economically and more satisfactorily electrically than by steam.

The difficulty is that few roads in existence have sufficient traffic to warrant such an investment in permanent way, and the result is that all of their traffic must be handled over one or two tracks, thus necessitating trains of all weights and all

speeds running upon the same rails. This results in a tendency to bunch the cars into as few trains as practicable, in order not only to reduce the cost of train service to a minimum but to give the fast-running trains greater headway to allow them to make their time safely. Such an arrangement of trains necessitates the concentration of large amounts of power in single units, which is leading away from the ideal conditions for the application of electricity to the propulsion of trains; and it is this element, combined with the fact that the traffic on most roads is not great enough to warrant the investment necessary in electrical machinery to produce and transmit the power to the distances necessary to keep a few heavy trains in motion, that makes the trunk line railway problem so difficult, as it is more economical to propel these heavy trains by steam-driven locomotives, which are practically portable power-houses.

It being admitted that electricity becomes most economical when a sufficient number of trains are available, and that the steam locomotive is most economical when the trains have become few and heavy, the problem then resolves itself into one of the density of traffic and the question then is: where is the dividing line?

It was my intention to attempt such an analysis of this subject as to be able to formulate some general law which could be readily applied to any given case, and thus enable one to decide whether electrical operation would be more economical than steam in any concrete case.

After carefully analyzing the subject I have become convinced that no general law or formula can be laid down which will apply to all cases, for the reason that the elements entering into different cases vary so greatly that any formula would contain too many variables, dependent upon local conditions, to admit of a general application.

I shall, therefore, only attempt to point out a way in which the dividing line between steam and electricity can be determined after the elements of each case are known.

It will readily be seen that with steam locomotive operation the fixed charges, and cost of fuel and engine labor increase almost directly proportional as the train miles increase, for in this case an additional locomotive means simply a given amount of increased investment, a given amount of increased fuel and labor, and this total investment is least when the number of locomotives is small.

On the other hand, with electricity it is necessary to invest at once a large amount of capital in the power houses and transmission systems, which amount must be great enough to provide for handling the maximum number of trains required upon the line, and unless this number of trains is great enough so that the economy effected in the different method of producing and applying the power is sufficient to offset the increased fixed charges, due to the additional invested capital, it will *not* pay to equip and operate electrically.

Any problem, therefore, must be analyzed for the relative cost in operation. In case this does not show a saving the advisability of equipping electrically will depend entirely upon the probable increased traffic to be derived from the adoption and operation of electrically propelled trains.

That electricity will be generally used on our main railway terminals, and ultimately on our main through lines for passenger and freight service, I am convinced, but I do not anticipate that it will always be adopted on the grounds of economy in operation; neither do I anticipate that it will come rapidly or through the voluntary acts of the owners of steam railroads, except in special instances.

At first the terminals will be equipped for special reasons, due either to the voluntary act on the part of the terminal companies to effect economy in operation, or to public pressure brought to bear upon the owners through an increased demand on the part of the public for better service, on the grounds that the use of the steam locomotive is objectionable in our great cities.

Those roads which run through populous countries will either build new roads, or acquire, for their own protection, those electric railroads already built and operating in competition with them, and utilize them as feeders to their through line steam trains. Thus the steam railroad companies will gradually become interested in electric railways and eventually become practically the real owners of them. With these roads operating as feeders to the main line system and with the terminals thus equipped and the public educated to the advantages of riding in electrically equipped cars, the next step will logically be the electrical equipment of the trunk lines between the cities already having electrical terminals.

Thus some favorably located trunk line having a sufficient density of population will feel warranted in equipping elec-

trically, and when this is once done the other roads running between the same competing points must, sooner or later, follow in order to hold their passenger traffic.

This may result in temporarily relegating some roads to freight service, so long as they operate exclusively by steam, but with the increased demand on the part of the public for better and cleaner service will come a corresponding increase in passenger revenue to the roads equipped for handling it until one road after another finds it advantageous to furnish an electric passenger service.

With the terminals and main lines equipped electrically, and the desire on the part of the public for more prompt and effective freight service resembling that which is given by the steam roads in England and on the Continent, due to the great density of population, there will be developed a great high class freight service conducted in light, swiftly moving electric trains which can be quickly divided and distributed over the surface tracks of our smaller cities, or through underground systems similar to that which is now being built in Chicago. Such a system would soon prove indispensable to the public and a source of great profit to the roads as it is now getting to be to many suburban railways.

This class of freight service would soon prove so large a part of the freight traffic of a road that the operation of the through freight traffic by steam locomotives, though at present cheaper, would in time, as the cost of coal increases, grow less, until those roads operating an electric passenger service would ultimately use electricity exclusively.

It has not seemed advisable to me in an address of this character to attempt to furnish detailed figures to support my theories for the subject is of such general interest that many able men are presenting papers upon it at the International Electrical Congress now in session here, in which papers will be found information of much value to those interested, and from which I believe the correctness of some of my assumptions can be proved.

The principal problem before the electric railway engineer to-day is how to make the most effective use of the high-pressure transmission, and high-tension working conductor and maintain safety of operation.

Experiments conducted during the past year by engineers in this country and abroad have made this problem simpler

than it seemed before and to-day we seem reasonably certain of the solution.

Until recently the cost of electrically equipping a trunk line under the standard direct-current, rotary converter system, has been such as to practically prohibit its adoption, but recent developments in the single-phase alternating-current motor field have made it possible to eliminate a large part of the investment heretofore necessary and the prospects for the application of electricity to long-distance running are better than ever before.

When it is recalled that the rotary converter, which was the means of reducing the cost of long-distance roads, was introduced in 1898, and that within the six years from the time of its adoption through the development of the single-phase motor it has been practically rendered obsolete for heavy railroad work, it will be seen that the dividing line between the steam locomotive and the electrically propelled train has moved several points in favor of the latter, due to the reduction which can now be made in first cost and the saving in operating expenses.

With the single-phase motor and the steam-turbine a reality, the transmission problem almost solved, and with the rapid development of the internal combustive engine now taking place, are we, as engineers, not warranted in believing that we can so combine them into a system which will ultimately supplant the steam locomotive in trunk line, passenger and freight service?

I do not anticipate that all roads will soon adopt electricity, for the steam locomotive will hold its field in this country for many years to come, but I do expect, judging somewhat from "positive knowledge," a remarkable development to soon begin in the electrical equipment of favorably located steam roads.

From Richmond, where the first commercial electric road was built, to the present is but 17 years, yet within that time the horse has been relegated to the past as a serious factor in transportation, the cable has served its usefulness and awaits its end, and the suburban railway has been developed and is now rapidly encroaching upon the field of the steam railway.

With the terminals of the two greatest roads in the United States now being equipped electrically and with an investment of something more than $4 000 000 000 in electrical industries

made within a quarter of a century, we have reason to feel satisfied with the past.

With several of the leading roads in this country, of England, of Sweden, of Switzerland, of Italy, and Australia electrically equipping branch lines and seriously considering changing large portions of their present systems from steam to electricity, we, as personal factors in this great industrial advancement, have every reason to be hopeful for the future.

Discussion on "Long Spans for Transmission Lines."

Ralph D. Mershon: At the bottom of page 558 Mr Blackwell says: "The deterioration of a line requires its replacement in from five to twenty years." Presumably Mr. Blackwell refers only to the structure supporting the line. His statement would not hold true regarding the conductors. Of course the whole line does not deteriorate in any such short length of time. On the next page he speaks of the steel tower acting as a lightning-arrester. A few days ago the speaker heard of one line which had been in operation for some time, the construction of this line being similar to that described by Mr. Blackwell. Iron rods were attached to the tower and bent up around the insulator in order to protect it from a stroke by lightning. Has Mr. Blackwell ever seen a similar construction?

Mr. Blackwell also says: "If one insulating support takes the place of four or five, line troubles will be reduced nearly in direct proportion; the inspection and repair of the line will be much simplified and its cost of maintenance correspondingly diminished."

The speaker's experience with line troubles has been that of having less trouble from insulators than from any other part of the construction. Most of the trouble has been caused by forest fires burning the poles; trouble has also been caused by short-circuits due either to wire thrown over the line maliciously or by carelessness in the construction work for extensions, etc.

When a line is first put up, it is almost always the case that a number of the insulators are broken maliciously; after a little while, the insulators are let alone, even in the West. One transmission line with which the speaker was associated crossed a cattle ranch; the cowboys used the insulators for targets, shooting off as many of them as they could. In a short time, however, that practice was stopped, for that class of men, if you appeal to them in the right way, can be easily approached and reasoned with. One of the line inspectors brought the matter home to them by saying that the breaking of one of the insulators might mean the killing of a man at another place, a man who, after touching off a blast, was endeavoring to reach the surface by means of an electric hoist. In that particular case, where trouble of this kind was the worst that the speaker has ever known, it was stopped almost entirely.

On page 557 Mr. Blackwell says: "Permissible tension in the cable must not exceed the elastic limit, by which is meant the point at which the material will continue to elongate and will eventually break, and not the usually accepted meaning of elastic limit. Now what is the difference between what Mr. Blackwell defines there and the ultimate tensile strength which he speaks of on the next page?

There is another matter of importance mentioned by Mr. Blackwell; that is, if a line carries a considerable amount of

power, sleet is not so likely to form on the wire. This is especially true of high-pressure lines. With a given loss, the higher the pressure the smaller the conductor and consequently the greater the loss per unit of radiating surface of conductor, and, so far as the speaker has been able to observe, a small variation in temperature from that at which sleet forms will prevent its formation.

F. O. BLACKWELL: Answering Mr. Mershon's question; of course the deterioration on a line is confined to the wooden parts. Poles, under unfavorable conditions, may rot out in two years. In some places, as in India, ants eat up the poles. In dry ground, with the right kind of wood, the life of a pole may be 20 years. Mr. Mershon also refers to some trouble experienced at Guanajuato which was attributed to lightning. They have had some insulators break there, but, as the speaker understands it, they do not feel certain that the breakage was due to lightning. They are experimenting, however, with an extension of the tower to form a lightning-rod which they will place at exposed points on their transmission system.

Regarding the elastic limit of materials used for conductors, our experiments show that all of them, including copper, aluminum and iron, take a considerable set when subjected to any strain, and that the amount of this set depends on the time during which it is subjected to the strain. The cable is a sort of spiral spring. It is more elastic than a solid wire and its elasticity depends a great deal on the number of twists in the cable, the size of the hemp centre, and other conditions. We used a hemp centre because we found by experiment that a metallic core took the strain to which the cable was subjected before the outer strands and broke first. This made the cable with a conducting core weaker than one made with a hemp core.

Regarding sleet, it is probable that the only time when trouble would be experienced on a transmission of any size is when the power is off the line. At other times there will be sufficient heat generated in the wire to keep it above freezing point. In the case of this Guanajuata construction the insulators were cracked and split open. There was nothing in particular to indicate lightning; they were not burned except so far as they would be by short circuit from the line current.

A. S. HATCH: Possibly the experience of 20 years may be of interest in tower construction. In May, 1884, a windmill tower was erected for lighting a section of Detroit; it was triangular in cross-section, 22 feet on a side at the base and tapering to a point. There are nine 18-ft. gas-pipe sections, the first three being of 2.5 in., the middle three of 2 in. and the top three of 1.5 in., making the total height 161 feet. Weakness has been found to be buckling of the pipe standards, due principally to wind-strains. The towers have not been good lightning-arresters since switch-cases have been punctured after a storm. At the base of the towers are switches to control

the wiring, the cases of which were connected to the tower; and after a severe storm, a switch would be found punctured, showing the lightning had either left the line, jumping to the case of the switch and thence to ground, in case the ground is moist, or, as commonly the case, the lightning leaving the tower for the grounded line. The most common class of tower in use is also triangular but of uniform cross-section, and is built of 2-in. and 1.5-in. pipe, a section being 8 ft. high and 6 ft. on a side. The girts are 1-in. pipe and braced with ¾-in. diagonal stay-rods. The base of the tower is a single pipe 15 ft. high on which is a fitting to which both the horizontal and brace supports are fastened. The towers are guyed in four directions by two sets of guy-ropes consisting of 0.5-in. steel strand fastened to wooden stubs. These towers vary from 150 to 175 feet high, and on account of being used in a city are preferable, but the taper tower is better for transmission purposes on account of avoiding the use of stubs. There is no side-strain except that due to the line-wires fastened to the tower and sometimes having a span of 250 feet from a pole.

CHAS. F. SCOTT: The subject covered by Mr. Blackwell is a most timely and important one. It is notable that this paper deals mainly with mechanical problems, and that those which are particularly electrical in their bearing are minor in number. In fact, after the electrical engineer specifies a few general conditions as to conductivity and gives his attention particularly to insulators, the rest consists of matters which pertain to mechanical and economical problems.

Mr. Blackwell has pointed out the principal causes of the interruption of lines as they are now constructed. The new type of construction moreover apparently removes in a large measure all the principal causes of interruption to service in present lines; this is a very strong argument for the tower construction.

The discussion in the paper with regard to the characteristics of conductors and making comparison between copper, aluminum, and iron are of much interest, particularly the data upon copper cable. The difference between the elasticity of the wire and the cable, the latter being, as Mr. Blackwell expressed it, in the nature of a spiral spring, is noteworthy. One of the elements in this type of construction is the probable change in length of the conductor due to temperature variation. If the conductor could be made a spiral spring or if the twisting of the cable could even be carried to a greater extent than it is in the ordinary cable, then the conductor might be given a great elasticity and the limitations which are reached due to the variable sag of the cable might, in a measure, be eliminated.

Mr. Blackwell did not state specifically the pressure which is used on the line to which he refers. The inference is, however, that it is 60 000 volts.

N. J. NEALL: Has Mr. Blackwell any data to show the value of steel towers as lightning-arresters compared with standard lightning-arresters? and does he know of any case where steel towers were struck directly by lightning and what happened?

F. O. BLACKWELL: The speaker knows of a number of transmissions using pipe poles. In general it would appear that there is less trouble from lightning with an iron than with a wooden construction. Should lightning actually strike the line it would naturally go down the first pole. It would do no damage to a metal pole but would shatter a wooden one. With wooden poles there was always evidence left in the burning of or splinters from the pole, but with an iron pole you might have a stroke of lightning and never know it, except for a short circuit on the line, or unless an insulator were broken, which is rather improbable.

N. J. NEALL: Let us assume a case of a 60 000-volt transmission line in a mountainous country, such, for example, as in the far West. How would the cost of steel towers compare with the best present wood pole construction?

F. O. BLACKWELL: The comparative cost of steel towers and wooden poles can hardly be definitely stated, as it varies with the locality and the conditions. In this country, a wooden construction would almost invariably be cheaper as the tower system would be about equivalent to a cost of, say $10.00 per wooden pole. The steel tower in the tropics, where wood will not last any length of time, is essential; in this country, the speaker considers the use of a metal construction preferable on account of its more permanent character. The use of steel for long-distance transmission will probably supplant wood in order to get a more permanent and reliable construction. Where there is more than one circuit on a pole the necessary distance between conductors—to avoid the danger of short-circuiting—requires such a long cross-arm that it is essential to use two wooden poles in order properly to support the cross-arm. This, of course, doubles the cost of a wooden pole-line but makes practically no difference in the cost of a steel-tower construction.

A cable is preferable to a solid wire because it is more reliable and more elastic. The cable is flexible, which makes it less liable to damage during construction and from the swinging of the conductor in the wind. Should one strand of a cable break the whole conductor will not come down and the broken strand can be repaired at any convenient time. With a cable we can use a more brittle wire which has a much greater strength per square inch than would be possible safely to employ were a solid conductor used.

Regarding telephone circuits, it does not appear to the speaker that there is any disadvantage in the use of a metal structure; in fact, there is an advantage in that it is impossible

for high-pressure current to leak from the tower wires to the telephone circuit as it could on a wet wooden pole, which is a conductor of high resistance, whereas the tower is always grounded. It is most undesirable to do any work on a high-pressure circuit when it is alive. Wherever possible, multiple circuits should be employed so that one of them can be cut out for repairs without interrupting the tower service.

WM. HOOPES: A few words may be devoted to the aspect of this paper towards the comparison drawn between aluminum and copper for work of this character. By inspection of page 561 of the paper, it would appear that a sag of aluminum of 53 feet may be expected in a 100-ft. span.

Two and one-half years ago, the Pittsburg Reduction Company erected on a bluff 300 feet high, on the Allegheny River, in one of the most exposed situations in Western Pennsylvania, four 1000-ft. spans of No. 0000 aluminum wire, for the purpose of determining what might be expected from such a span.

Observations taken on these spans on June 17, with a temperature of 80° fahr., showed a sag of 22 feet. As the sun was shining at the time the observation was taken, the temperature of the wire should be taken as 105°, using the figure assumed in the paper as being correct; *i.e.*, that the wire would be 25° hotter than the air, due to the sunshine. The minimum temperature since the spans were erected was –14°, making a total range of temperature between the minimum and the time of observation of 119°. The paper assumes that a further rise of temperature of 56° may occur; if it does, the sag of the wire will be 27 feet. There is therefore considerable discrepancy between what actually has happened in such a span (which is about representative of what is likely to occur) and the 53-ft. sag which the paper says may be expected.

The reason for this discrepancy is the difference between the conditions which have actually occurred and the conditions which the paper contemplates as possible. The conditions contemplated by the paper are:

1. That the wind will blow with an actual velocity of 100 miles per hour.
2. That such a wind velocity will be coincident with minimum temperature.
3. That the direction of the wind will be at right angles to the line.

If any section 100 miles square were selected and a pole line built across it, by assembling what data is available from the U. S. Weather Bureau and applying the theory of probabilities, we would find that a combination of these conditions is not likely to occur oftener than about once in 20 000 years.

The Government reports give the velocities as actually indicated by the standard anemometer. These figures require a considerable change to convert them to true velocities. One hundred miles actual velocity would be reported as 135 miles

per hour. Such a velocity is almost unknown in the annals of the Weather Bureau. A search of the Bureau reports for six years shows for 28 widely scattered stations a maximum indicated velocity of 86 miles, or an actual velocity of 68 miles per hour. None of the maximum velocities have occurred coincidently with low temperatures and it does not seem within the range of probability that they will so occur. The maximum velocity occurring in Chicago last winter when the thermometer was below zero was 38 miles per hour indicated.

The only wind which actually seems likely to do harm to a line of this character is a tornado, and which it is impossible to erect any line to withstand, since the effects of tornadoes have been observed which must have been due to an actual velocity of 300 miles per hour, or a pressure of 360 pounds per square foot. Provision against this would involve a cost of construction absolutely prohibitory. Aside from the tornado the most severe condition a long span line is likely to be called upon to withstand, so far as wind strain is concerned, is a wind velocity of 40 miles per hour, occurring at from 20 to 30 degrees above the minimum temperature.

Although the conditions assumed in the paper seem unlikely to occur, it is worth while to consider what would take place with a line not designed to meet these conditions but to meet those which actually seem probable. Such a line using aluminum of the size referred to in the paper would be erected to have a sag, at minimum temperature, of 13.25 feet, and a tension of 11 000 pounds per square inch, the elastic limit being 14 000 pounds per square inch. If in that condition it were subjected to a 100 mile wind, at right angles, the effect would be to stretch the wire, not to break it, so that a sag of 42 feet would take place, which upon cessation of the wind would become 38 feet.

The effect upon the wire would be permanently to stretch it about four feet. It will withstand an elongation of 16 feet before rupture, and there really exists, therefore, a factor of safety of four, against breakage, even when the improbable conditions here chosen are used as the basis of calculation.

It is to be noted that in the case of spans of wire, the real factor of safety is not the ratio between the strength and the strain, which is the usual definition, but the ratio between the elongation at rupture and the possible elongation.

With regard to the strains due to sleet, there seems to be no limit to the amount of sleet which may gather on wire and it is very doubtful if the assumption of a depth of one inch for the deposit provides for the probabilities. If it is to be considered at all, a greater thickness should be considered as possible. However, the opinion of most practical transmission engineers, based on experience, seems to be, that sleet does not form on high-tension wires, and that its consideration does not therefore constitute an element of the problem

With regard to the necessary strength of supports, and therefore their cost, the most severe requirement is most lightly touched on in the paper. This condition will be when, for any reason, all three conductors part in the same span, leaving the unbalanced strain to be taken care of by the supports, which supports must be strong enough to withstand this strain, as in the event of such an occurrence several miles of the line might go down, if they are not so constructed. If the supports are made strong enough to meet this condition, they will be amply strong enough to meet the wind strains calculated, since the side strains due to the wind are less than one-fifth the longitudinal strains produced by this condition. It also becomes apparent in this connection that, if a maximum strain per conductor of 5000 pounds for copper and 2500 pounds for aluminum is allowed, the towers will have to be twice as strong for copper as for aluminum. If, on the other hand, the strain per conductor is to be kept down to 2500 pounds, the maximum sag of the copper will be about the same as that of the aluminum, instead of about one-half as much, as shown in the paper. The expediency of allowing the amount of sag designated appears very doubtful, since, if the improbable conditions assumed do occur, the only effect will be, not to break the wires and interrupt service, but to introduce a sag, which can be removed at leisure. To allow the amount of sag calculated, if not necessary, forfeits considerable advantage, because if such a line were constructed on 75-ft. towers, for instance, and a sag of 50 feet allowed, the wires at the center of the span, being only 25 feet from the ground, could easily be short circuited by malicious persons. On the contrary, if a sag of 30 feet only be allowed, (which is all that is probably necessary), a clearance of 45 feet is obtained, and malicious interference becomes very difficult, and, therefore, improbable.

It would appear to be the best practice on a line of this sort, to erect the conductors so that they would reach a maximum tension at a minimum temperature of about 80% of their elastic limit, without considering the wind as a strain producer. If this is done, it will be only on very rare occasions that the wind or other causes will permanently stretch the wires and produce a greater sag than is contemplated, and this, when it does happen, will be on short stretches of the line only, making repairs a matter to be done at a convenient time and at very slight expense.

One result of following the method of calculation in the paper is that the sag to be allowed for every different size of wire would be different, although the wire is of the same material. This is because the wind pressure varies directly as the diameter of the wire, while the strength to resist the wind pressure varies as the square of the diameter. If the calculations on which the paper is based had been made for No. 1 copper, instead of No. 000 copper, the results would have been entirely

different and the maximum sags to be provided for very much greater.

F. O. BLACKWELL (by letter): Referring to Mr. Hoopes' comments, the writer affirms that it was not his intention to lay down any rules for the sag employed in long spans but to give the data and formulas which can be used in figuring upon them.

The maximum strain in the conductor and the wind pressure which should be assumed are matters of engineering judgment. A wind pressure of 40 lb. per sq. ft. is that commonly employed in making the calculations upon practically all engineering structures, and, therefore, the writer would not take any less pressure without further data on the subject. A long-distance transmission line may cover a great deal of territory and if there is any high wind it is most likely to be interrupted by it. The fact that an isolated span with much less sag has been up for two or three years does not necessarily prove anything. The probabilities are that at the particular point at which the experimental span was erected no high winds have been experienced.

It does not impress the writer as being good engineering to put up a long span and then let it take its own sag by stretching the wire as Mr. Hoopes suggests, any more than it would be advisable to do the same thing in a suspension bridge.

The writer does not agree with Mr. Hoopes regarding the strains to which towers are subjected lengthwise of the line. The ordinary tie-wire which attaches the conductor to the insulator will not bear any considerable strain. If a conductor breaks it always slips over the insulators for a considerable distance on both sides of the break and distributes the strain, due to the tension in the conductor, over a number of insulators and towers. As Mr. Hoopes states, the amount of sag to be allowed varies with different sizes of wires. Each transmission must therefore be calculated separately and no tables or curves can be given which will cover all conditions.

EUGENE CLARK: The speaker is particularly interested in the paper by Mr. Blackwell, because he argues for better mechanical strength in the pole line, which is generally conceded to be the weakest point in an electrical system. The speaker thinks it possible, however, that Mr. Blackwell might have left the impression that line construction with steel poles would be just as cheap as similar construction with wooden poles, and if this were true, he wishes to offer a correction to that impression. The speaker objects to the figure of $10.00 a pole which Mr. Blackwell has submitted as the equivalent in wood, of steel construction, The speaker knows that steel poles have long been in use in many steel plants of the country, not for the purpose of securing longer spans for light wires, but for the purpose of securing better mechanical construction for the exceedingly heavy lines necessitated by the large amounts of power carried at low pressures in such plants.

That the cost of such poles, which are quite heavy, varies from $60.00 to $120.00 each, erected, including cross-arms, concrete foundations, etc. One steel company has recently had occasion to cross a navigable river, and to do so found it necessary to put up very high steel towers. In this case, the total cost of each tower amounted to more than $1500.00.

The speaker believes thoroughly ,however, in the advisability of the superior mechanical construction made possible by the use of steel poles, calling attention to the fact that moving machinery, such as cranes and hoists, is commonly designed with factors of safety of from 5 to 8; whereas, the factor of safety on pole lines, as frequently constructed, scarcely amounts to 2 or 3 for ordinary service. The factor of safety should be at least as high on a pole line as on moving machinery.

PRESIDENT ARNOLD: The New York Central engineers also investigated pretty thoroughly the matter of steel poles. They began with steel poles that cost approximately $200 each; by dint of much effort they were finally estimated to cost about $80 each. The argument in favor of steel poles is strongest for the long-distance transmission lines running across country where the poles can be spread as far apart as will be justified by mechanical consideration. In cities the poles must be placed close together, necessitating the use of a larger number of steel poles per mile of line than would obtain in the country; this increases materially the cost of the line as obviously steel poles cost more than wooden ones. As Mr. Blackwell says, where the wooden poles are expensive, as in Mexico, the transportation of wooden poles is likely to make them cost as much or more than the steel towers. On the Guanajuato plant the cost was much less with five steel poles to the mile than it would have been with wooden poles spaced the ordinary distance apart. So the question is always one of the relative cost of wood versus steel *in position*. In the speaker's opinion there is no doubt about the desirability of steel poles; the question is rather one of getting sufficient poles to carry the line at a price that will justify their use.

The engineers of the New York Central road have decided upon overhead transmission for most of the line and for these two reasons: first, less first cost; secondly, the likelihood of less trouble with overhead lines than with underground cable—all this notwithstanding Mr. Carlton's statement. His statement is undoubtedly correct, but it seems that he refers to a specific case. The evidence in the New York Central case showed that they might expect less trouble with overhead transmission lines running across country than with an underground cable. For these reasons cable is being installed only in New York and its vicinity, where the use of cables is practically compulsory. A pressure of 11 000 volts will be used on this system. There will be six wires, two circuits, and the spans will be made as long as the conditions will admit. There

is quite a number of curves in the track which necessitates putting the poles closer together than in an ordinary construction. The bridge engineers of the company are figuring the relative cost of poles; the poles are approximately between 16 and 18 inches at the base and 45 ft. high.

In further explanation of why the engineers of the New York Central adopted the overhead plan it might be said that the possibility of trouble on the line was taken into consideration; for with overhead construction trouble can be located and remedied quickly and easily, much more so than would be the case with an underground cable. The objection to cable seems to be that when anything happens the trouble can be neither located nor repaired promptly.

EUGENE CLARK: It does not make so much difference about the angle-iron, if the rails are good in the first place, but the construction of the pole must be rather unusual. The common poles that the speaker referred to as costing $60 and $120, consist of four irons latticed together, on the other side with rounds to form the ladder. The speaker does not see how you can get that amount of steel in for $15, if it is steel.

W. D. BALL: The South Side Suburban Railway Company of Chicago has ordered a few poles on trial, and information regarding their cost and weight may be of interest. The poles in question were 30 ft. high, weighing 616 lb. each, and the price f.o.b. cars Chicago or vicinity was a little less than three cents a lb. The actual cost of the pole is considerably less than any other type on the market, as it weighs less for any given strength and the cost per lb. is a trifle less, as tubular poles were quoted from three to three and a half cents. The construction consists of three U-section steel uprights tied together with special malleable castings every two feet or 30 inches. The poles in question were six inches, at the top and thirteen inches at base.

RALPH D. MERSHON: There are two matters in connection with steel towers which have not been referred to; one of them is the amount of torsion that the steel tower shown by Mr. Blackwell can resist in case one or more of the conductors should break. The speaker knows of one instance where a latticed steel pole was erected, where no allowance was made for torsional stresses with the result that every time a wire broke there was considerable trouble.

Another matter in connection with steel supporting structures with long spans is the question of repairs. A span of say 150 feet is easier to repair than a much longer span; this means that in case of a break in the line the power service will be interrupted for only a comparatively short time. In comparing this type of construction with other types the first cost alone should not be considered; we should consider everything which goes to make up the total cost; first cost, maintenance, etc.

It seems to the speaker that there is one point in which the steel tower construction falls short of what is claimed for it. Although it is true that the conductor will, for the greater part of its length, be higher than an ordinary pole-line, still with the construction described by Mr. Blackwell, the conductor is only about 25 feet from the ground, making it easy to short circuit the line at this point with a bale wire as in the case of a shorter span and lower pole.

N. J. NEALL: The following facts should be borne in mind with respect to the development of steel towers; some of the more recent wooden pole constructions are very stable; a number of lines have been built with a great deal of attention to the mechanical features, heavier poles and greater strength throughout, and the maintenance of an almost continuous line service for a year or more would indicate that the wooden pole line has been developed very materially. When you have such a construction near the base of supplies, it may require more than the arguments brought out to-day to substitute steel towers for wood. In the case cited by Mr. Blackwell where wood is as difficult to obtain as steel, it is perhaps more economical to make use of the steel tower. In cities and their outlying districts still other conditions enter, and it might be easily advisable that the tower construction, even though more expensive, should be employed.

In addition to the emphasis given the advantages pointed out by Mr. Blackwell for metal towers, it does not appear from the discussion that the cost of such a tower construction is, broadly speaking, prohibitive. The advantages of the metal tower as a lightning-arrester seem to be unduly emphasized. The metal tower might be considered as having approximately the same discharge value as an overhead grounded wire on a wooden pole-line, and it is obvious that in view of the fractional value of such protection we are in no degree relieved from having protective apparatus in the stations. The discharge value of the metal tower seems only incidental to its other advantages.

CHAS. F. SCOTT: We are getting on the wrong line of discussion with reference to Mr. Blackwell's paper. While the cost, the relative cost, of the two different types of construction is an important thing to consider, it is not the only thing. Mr. Blackwell does not begin his paper with the consideration of cost or to find something that is cheaper. He begins it: "Unfortunately interruptions of the power service occur not infrequently and when they do happen they so inconvenience the public as to be most conspicuous."

It is a better kind of service, a different order of construction that he is seeking for; he finds out how that construction will overcome present difficulties. Sometimes cost is important; sometimes it is relatively unimportant. A few years ago an engineer who was making a preliminary layout of a trans-

mission plant asked the speaker what he thought of the engineer's transmission system; it was 20 miles in length, and he proposed to use one pole line and two circuits of 30 000 volts. The engineer was told that his pressure was very high and he was putting a good deal on a one-pole line, and as he wanted reliability he would better consider lower pressure and two separate pole lines. The cost of the line complete, conductors, poles, insulators—the whole cost as the speaker remembers—was something like four per cent. of the total investment. Here, then, was the element in the system upon which the continuity and reliability of service depended—the most vital element in the whole system, and he had gotten it down to four per cent. of the whole investment. By increasing that element, say doubling its cost, and running two pole lines say of 20 000 volts each, he would increase his total cost only a few per cent. and he would increase his coefficient of reliability by a very much greater per cent. So in the general question now under discussion, we have to consider, first the general engineering condition, which would be the best plan and would give the most reliable service; and then determine as to the cost. This paper should be considered on its general engineering merits, and it seems to the speaker that Mr. Blackwell's points are pretty well taken.

Another thing: we have been comparing a new type of construction with certain lines and poles now used. We are coming into a different order of conditions in power transmission—the circuits are of greater output, higher pressure, and greater importance. Where there are many circuits, with large and heavy wire, where continuity of service is of the utmost importance, where the cost of the line could often be considerably increased in order to increase the coefficient of reliability, then we must consider the problem from an entirely new standpoint. In these respects the lines laid down in this paper are very promising.

F. A. C. PERRINE: While agreeing entirely with Mr. Blackwell and Mr. Scott in the statement that reliability is more important than cost in long distance transmission, the speaker believes that a number of points raised by Mr. Blackwell require consideration.

As regards the limit of transmission with any particular size wire it may be noted that up to 40 000 volts no wire of sufficient strength to be employed in a transmission line is small enough to allow discharge through the air, consequently allowing the rule that the practice in transmission pressure is to employ about 1000 volts per mile. The question of limiting size of wire is not of importance until the distance exceeds 30 or 35 miles. For longer lines where the pressure is between 40 000 and 60 000 volts no wire smaller than $\frac{3}{8}$ in. in diameter may be used; since Mr. Scott has already shown in the paper referred to that at such pressures a wire $\frac{1}{4}$ in. in diameter will discharge

a large amount of energy. This necessity for the use of a large wire on long lines is one of the advantages in the use of aluminum, an advantage not noticed by Mr. Blackwell in his paper. This is particularly an advantage of aluminum, since where small amounts of energy must be transmitted over a wire of a definite size the loss is not important, and the aluminum wire is very much cheaper than the copper wire of the same size. These large wires are invariably made stranded, as in this form they are more reliable than any solid wire of the same area, on account of the fact that the smaller wire has a high tensile strength and by reason of the fact that the weak places are distributed along its length. The writer believes that Mr. Blackwell is in error when he states on page 557 strands are made of unjointed wire. The practice amongst manufacturers being to joint reel after reel in their machine, cutting off the completed strand in the required lengths without reference to the lengths of wire on the spools of the machine which are jointed as required. Experience has shown that the large strand which must be employed in very long lines gives no trouble in breaking.

The speaker knows of very few instances where strands of over 0.5 inch in diameter have been burned off; the few cases occurring have been due to a solid short circuit where the station fuses did not operate, but it is generally the case that the station fuses operate before the line wire is fused.

Attention must be called to an additional advantage of tower construction, that it permits the use of large cross-arms supporting the very heavy insulators which must be used in the higher pressure construction. Insulators at present weighing from 30 to 50 pounds are common, and with electrical pressures increasing the present tendency is toward larger insulators weighing as much as 100 pounds. Some insulators now in use cannot be installed on a wooden cross-arm less than 6 by 6 inches, which arm cannot be securely supported on a wooden pole with a 9-inch top. In consequence the steel tower, whether the cross-arm be of steel or wood, is probably capable of furnishing the more reliable type of construction, since in long-distance transmission lines we must decrease the number of insulators by lengthening the spans and correspondingly increase the size of the insulator. This can only be accomplished by the use of the steel tower.

The value of the steel tower as a lightning-arrester the speaker considers very important. He believes that to-day the advantage from the use of a grounded wire for protecting the long-distance transmission lines is unquestioned, though there is decided difference of opinion concerning its permanence; but with the steel-tower construction a sufficient number of grounded points are brought close to the wire without the use of an extra wire. On one transmission line with which the speaker is familiar there is a section 37 miles in length where the average

span is 300 feet; this section is one-third of the line and extends over a series of low hills. Such lines can undoubtedly be made more permanent if steel towers are used in place of the wooden poles. While not an advocate of the steel-tower construction for short lines and low pressures, the speaker strongly believes in the steel-tower construction for long lines and high pressures; first, because of the increased value of insulation by reason of a lesser number of insulators; secondly, because of the lightning protection afforded; thirdly, because of the permanence of the towers themselves, and because of the fact that they allow the use of a cross-arm which will support a larger insulator and a larger wire.

Finally the speaker would call attention to what he believes to be an error in Mr. Blackwell's Introduction, pages 560 to 562, where he makes use of the standard coefficient of linear expansion in calculating the temperature changes. This is not correct unless the modulus of elasticity is introduced into the equation, which then becomes too complicated for solution. If a fictive coefficient of expansion based on experiments at different temperatures with actual spans, then the form can be considered correct.

The equivalent cross-section of a solid wire will have a lower tensile strength than a strand, because the wires of a strand have been subjected to an increased amount of working and are consequently harder. Furthermore the weak places in a strand are distributed. In consequence the strength of a strand is proportionally more than one would expect from the decreased size of the wire.

RALPH D. MERSHON: Does Dr. Perrine mean that the ultimate strength of the cable will be greater than the sum of the ultimate strengths of the individual wires?

F. A. C. PERRINE: Yes; so far as the speaker knows, with copper, with soft strands. That is absoultely untrue with steel, with metal that will not crush.

EUGENE CLARK: The speaker calls attention, as being of interest in this connection, to the fact that hoisting ropes used on cranes built to handle molten metal have been made with cores of soft iron wire, or of asbestos, it being necessary to use a fireproof material. In practice, it is found that the strain on the ropes acts to extend the helices formed by the outside strands of the rope. In the case of asbestos-cored rope, the core would break at various points throughout the length of the rope and separate, so that sometimes 18-in. or 24-in. space intervenes between the two broken ends of the core. The result would be to allow the rope to flatten at that point. In the case of the soft iron-cored ropes, the iron core was cut out of the rope at each end. When the rope stretched, the iron core was stretched enough to pull through and leave the open space at each end of the rope, where it caused no damage. In view of these facts, the speaker feels convinced that a central straight strand for a

transmission cable would certainly receive more strain than the outside strands.

RALPH D. MERSHON: It seems to the speaker that Dr. Perrine overrates the question of lightning protection from steel towers. The speaker does not see how a steel tower can be the equivalent of a ground-wire, nor how a steel tower can ward off electrostatic induction. The tower might take a lightning stroke, but it does not seem that it could be of any protection from effects due to electrostatic induction or from lightning strokes which might get into the line-wire. In the latter case the charge will probably jump to a pole, but in doing so will probably shatter an insulator. The speaker does not recall any case where a wooden pole has been shattered by lightning where the insulators on that pole have not, one or more of them, been shattered. It isn't a case of simply flashing-over the insulator, nor is it a case of flashing-round or yet a case of puncture. In most cases the insulators go all to pieces; the speaker knows of one case where a pole on a high-pressure line was struck by lightning and an insulator smashed to pieces; the French Canadian patrolman who reported upon this occurrence said in his report: "I found pieces of her over in the field; if she had been hit by a stone she would not have gone so far."

Dr. Perrine and Mr. Scott have both said the cost is not the important question. This the speaker cannot agree with, for he believes that cost is the only question; not necessarily first cost but the total cost, including interest, depreciation, etc. Into this cost must enter and be considered the question of reliability, a question which cannot easily be evaluated in dollars and cents. Its weight and valuation must enter into the calculation through the medium of the engineer's judgment. It is easy to imagine a situation where, with a type of construction subject to mishaps resulting in interruption to service, a plant might be a commercial success in spite of occasional interruptions, but where the cost of absolutely reliable service would swamp the enterprise; on the other hand, there are situations where anything less than the very best and most reliable construction would swamp it. It is all a question of cost, and of cost proportional to the conditions to be met.

W. B. JACKSON: The speaker fully agrees with the statements that the iron tower would seem to be excellent as a lightning protection.

The speaker does not agree with Mr. Mershon that the lightning in jumping around the insulators as a rule breaks them. For instance, in a 20 000-volt transmission line, with which the speaker is familiar, the lightning has struck the line a number of times and smashed one or more poles at or near the point of striking and has then run along the line each way jumping around the insulators for several poles consecutively, slightly splintering the poles. It was seldom the case that the insulators were broken in the discharge of the current over

them. It was usually possible to replace the broken poles by setting a new pole immediately alongside of the broken one and transferring the cross-arm and the pole-top insulator without further repairs. In the case of the steel towers there would apparently be little tendency toward the destruction of the tower, and should the lightning strike the line it would have a tendency to run along the line and relieve itself over the insulators at the adjacent towers.

Referring again to the line mentioned before; it was not infrequently struck at points between the lightning-arrester stations, and sometimes struck hard without any indication whatsoever of the discharge getting as far as the lightning-arrester stations, though indications of its leaving the line over the insulators was amply abundant.

As already indicated it is entirely possible that the lightning might strike between the supports in the case of iron towers and run either way along the line, dissipating itself through induction and by discharge to the towers. Of course the exact action under these conditions cannot be predicted with any certainty, especially as with the steel-tower construction we generally associate the higher pressures such as 60 000 to 80 000 volts, and so must solve the problem according to our best judgment considering that we have no operating data to work upon—but we must always remember that lightning works according to ways other than our own.

There is another feature in connection with the tower construction that has been brought out a very little this morning, that would seem to warrant further consideration. It has not been uncommon on 20 000-volt transmission lines and even 30 000- and 35 000-volt lines that a wire of the transmission circuit has dropped on to the cross-arm carrying wires and no one has been the wiser for the fact until the line inspector discovered it. In the case of the steel tower, the dropping of one of the wires upon the support might be indeed serious, owing to the fact that the wire would probably be burned off at the point of contact, with disastrous results; thus the problem of the mechanical strength of the insulator and the attachment of the cable thereto is of paramount importance. As Dr. Perrine has pointed out, there is extremely little chance of a properly constructed cable breaking except under abnormal conditions, therefore, the absolute certainty of support of the cable is of the greatest importance, for if there is danger of the insulator breaking, or the attachment of the wire to the insulator giving way, the possibility of the wire being burned off would be considerable. With the long spans and heavy cables that would usually be contemplated in connection with steel towers, the breaking of the wire might be a catastrophe of real magnitude.

Except in extraordinary situations, the speaker's feeling is that a well-constructed pole line using wooden poles and wooden

cross-arms must continue to be the most satisfactory construction for transmission lines, so far as general practice is concerned in this country.

A conversation which the speaker had with Mr. Blathy of Ganz & Company at Budapest may be interesting: he remarked that it would be unwise to attempt to employ 35 000 or 40 000 volts in accordance with the usual European practice in transmission work considering the status of the insulator at that time, and asked: "What do you think would be the best to do under the circumstances?" My reply was, to use the usual iron poles but attach wooden cross-arms to them. He replied that they would not permit such unsightly construction as this would necessitate, though he felt that the wooden cross-arm was a material advantage.

H. B. ALVERSON: In regard to lightning on lines of 11 000 volts and 22 000 volts, our experience has been that where it struck, the insulators would be shattered. Either way from this point the insulator would usually be punctured, while slightly farther away no damage would be done. At the time when the lightning struck the line, the circuit would be short circuited, undoubtedly at the point where it struck. In the case of a steel tower line this would probably cause the shutting off of current before enough time has elapsed to burn off the cables.

PETER JUNKERSFELD: Mr. Mershon's statement that cost of the transmission line is everything, cannot, it seems, be generally accepted without some qualification. If the owners or managers of the line are interested simply in receiving and delivering power without much restriction or responsibility, the statement might hold. In that case, however, it is only a temporary or perhaps expedient commercial organization, because for ultimate and permanent success we must consider everything all along the various steps from prime mover to the individual consumer.

"Reliability of service" is a term that must be used relatively and usually should be the first consideration, the second being the securing of such reliability for the lowest permanent annual expenditure. This reliability of service is always extremely important. In large cities even with the principal high-pressure transmission underground, this represents a comparatively small part of the total investment in the central station system, and it would seem unwise even for some considerable difference in total cost of high-pressure transmission to take chances with the particular part of the central station system which represents perhaps the greatest responsibility and least annual expenditure per unit of output.

Similarly in the New York Central's present undertaking, the cost of high pressure transmission must be small compared to the total when we consider car equipment, track construction, power and substations, and so on. For reliability let us

compare a duplicate overhead line, six wires on the same set of poles, with a duplicate underground line both in same group of conduit, assuming best construction in each case. In both cases the conductors are heavy enough so that loss of one line will not interrupt the service. Assume now that probability of breakdown in insulation of conductors is nearly equal in the overhead and underground construction, the probability of external injury of all possible kinds is very much greater with the overhead lines. In event of serious short circuit on one line, the probability of both lines being disabled, resulting in a total shut-down of lines, would seem greater with overhead construction, as the two overhead lines on same pole cannot be isolated, while the underground lines can. Experience and observation would indicate that ordinarily with transmission at 11 000 volts, good underground construction would be much more reliable.

In the question of overhead and underground transmission for the particular case of the New York Central, it is probable that there were a number of unusual conditions not generally known. The estimated cost of underground being seven or eight times that of overhead construction, indicates at least one very unusual condition. The annual expenditures, however, on account of transmission lines operation and maintenance, would not be in the same proportion.

PRESIDENT ARNOLD: Mr. Benezett Williams has requested that the speaker ask this question:

"What would be the effect on the permissible voltage by the protection of the insulators and cross-arms from rain, snow and sleet; that is, how much above 60 000 volts could the pressure be carried?"

The general question is, what kind of protection should the insulators and cross-arms have from rain, snow, and sleet?

F. A. C. PERRINE: The speaker wishes to present a proposed construction for discussion; this construction is designed for a 350-mile, 80 000-volt line. On investigating it was found that a 14 by 14 insulator was small enough for 60 000 volts, but it was a question whether any reasonable-sized insulators for use out of doors could be made for 80 000 volts. Furthermore, it was found that with a duplicate three-phase line, if one line was out of service for repair the regulation of a single line would be so bad that the service could not be maintained. In other words, in trying to get along with half the copper the regulation would be too bad to give any kind of service. Consequently a system was proposed involving the erection on a tower of a house about ten feet square with four wires on insulators in separate compartments each being five feet square and ten feet long, the idea being to put the insulators in an enclosed house having four wires all told; three wires being in service at any one time, the other wire being out of service for cleaning insulators and for repair. In that way enough metal

could be concentrated on three wires to ensure regulation. In addition the tower was to be provided every 10 miles with a switching station, so the service of any one wire could be switched on any of the four.

In regard to the covering of insulators, the Kootenric Company in British Columbia has built a line with a pent-house over each insulator but from this they have not derived any very great advantage, for while the pent-house protects the insulators against rain or snow it does not protect them against dust and fog; the combination of dust and fog makes mud, producing the worst possible conditions. In estimating this line, 18 000 volts were figured on.

H. C. WIRT: Will President Arnold say whether the New York Central lines are to be operated with the Y connection grounded? There seems to be a difference of opinion in reference to the advantage of operating in this manner.

PRESIDENT ARNOLD: No; it is not intended to run it under abnormal conditions; provision is made in the power-houses and sub-stations for grounding whenever the engineers see fit to use the ground wire.

N. J. NEALL: Dr. Perrine has brought out very justly the advantages shown by Mr. Blckwell's paper, and moreover the discussion has brought out the fact of a cost that is prohibitive; but it seems that in addition to what has been said as to the advantages electrically, it is not out of the question from a financial standpoint. One matter seems to have been given undue emphasis; that is, the lightning protection. Last year at Niagara we were discussing the advantage the barbed-wire or the ground-wire had over the transmission, that it was a good thing to take off some of the static discharges. You must remember that when you have a climatic disturbance you have an electrostatic disturbance, and an electromagnetic disturbance. The steel tower, and for that matter the barbed-wire protector, does not in any degree relieve us from having protection in the stations. And the electrostatic can be taken to some extent by the entire line, but only incidentally. The best protective apparatus to-day provides for the discharge of this disturbance as well as the electromagnetic. We cannot consider the steel tower as having anything more than an incidental advantage, but they are better than wooden poles because they will absorb from the atmosphere some of the static disturbance.

F. O. BLACKWELL: There is another thing in connection with steel-tower construction. The towers can generally be located on high ground, so that the maximum sag will occur over the low ground between towers. A tower would naturally be located at the highest point—on every hill which is passed over—these are the points which would naturally be struck by lightning, and the towers, if especially provided with points projecting above the line, will take a lightning charge without

affecting the system. Wherever there is a sudden change in altitude, or other conditions which cause lightning phenomena at certain points, there should be lightning-arresters connected to the circuits which will discharge them to ground.

N. J. NEALL: In consideration of the relatively great distance between cloud and line, the addition of lightning-rods to metal towers would probably not be as effective as Mr. Blackwell suggests, and hence for any direct strokes the metal towers should be able to attract and discharge these disturbances as well as if equipped with lightning-rods.

H. C. WIRT: Reports received from a few plants where ground-wires are used indicate that such wires prevent the shattering of the wooden poles and they also assist to protect the apparatus at stations and sub-stations. If the interruptions due to shattering of poles are frequent, it may be necessary to use ground-wires.

N. J. NEALL: Is the case referred to by Mr. Wirt regarded by him as general or special, because there have been plants where transmission lines have had their poles shattered and the continuity of service not disturbed. Any questions regarding overhead grounded wires are meant solely to bring out their value, not to disparage their use. If lightning has shattered poles and disturbed the service then any protection of the pole to eliminate this is indeed valuable. It seems too early to decide the worth of overhead grounded wires, and we must certainly wait until those who have had the courage to install this system and investigate its behavior report their observations; and even then to be of permanent value these observations must cover a wide geographical area and have lasted for more than one lightning season. So far these observations have been special. If we should take up the metal tower, then overhead grounded wires would probably not be used.

S. B. STORER: One of the speakers said in referring to the use of barbed-wire that he frequently obtained an extra high pressure between any two transmission lines. Now if a barbed-wire is added to the transmission line it seems to the speaker that the trouble is increased about one-third, because the same pressure might obtain between the grounded wire or between the barbed wire and the transmission wires that would obtain between any of the transmission wires.

H. C. WIRT:—Theory or laboratory tests should not be relied upon wholly in the design of lightning-arresters. We will have to work with the lines themselves and make extensive trials on any protective device that may be proposed. Recent examination of transformers that have burned out has shown that a very high pressure has existed from line to line. Attention is called to a photograph of a connection board printed in the speaker's paper. The tension necessary to make an arc go across the terminals was 42 000 volts, and the working

pressure was 2000 volts. Too much attention has been given in the design of lightning-arresters to provide an easy path to ground and too little to prevent a rise of pressure between line and line.

In low-pressure work we started with transformers using insulation between primary and secondary that would withstand two or three times the working pressure. We now have to insulate our transformers to withstand five times the working pressure of 2000 volts. With these modern transformers we find that the burn-outs due to lightning effects are from line to line and rarely from line to ground. With high-pressure transmission lines it would seem to be necessary to provide a path from line to line as well as from line to ground so as to prevent the lightning current making its own path through expensive apparatus.

In many cases reactive coils were used for protection. It is possible to have an electromagnetic effect in the line wires; that is, upon a heavy stroke of lightning passing to ground high-pressure currents are created in the transmission system.

R. F. HAYWARD (*by letter*): Since the commencement of transmission work in Utah the writer has maintained the opinion that structural strength and stability are the first requisites for transmission lines. Every year's experience has strengthened this opinion. There are now 500 miles of transmission pole-line in Utah, and experience has abundantly proved that the line which is mechanically strongest gives the best service.

Glass insulators are not mechanically strong enough, nor will they stand the continued stress of heat and cold. Wooden pins should not form part of a strong line. Iron pins have been used on all the corners of the Pioneer line between Ogden and Salt Lake, and there has been no failure on their account in seven years. Porcelain insulators have stood the test of strength thoroughly well. Where properly designed and made, they do not check or break except when shot, and then they only chip instead of flying to pieces like glass. In only two or three instances have short circuits been caused in the Ogden-Salt Lake line by insulators broken by a rifle shot, out of thousands which have been chipped by bullets.

On a transmission line, the failure of one pole or one insulator may cause an interruption of service and therefore the factor of safety should be very large. A line designed for 50 000 volts can be depended upon for 30 000 volts. If a transmission line cannot stand the cost of an expensive porcelain insulator there can be no profit in building it. There is little excuse for interference from trees, but it is more difficult than might be supposed to get rid of trees in settled districts. In eight years' service on the Ogden line the greatest amount of trouble has been caused by burning of poles from brush fires. Careful patrolling has kept the interruptions from this cause down to a very small amount, but on one occasion 15 poles

were burnt off in a sage-brush fire. In a few cases poles have been splintered and insulators shattered by direct lightning strokes. Except in these instances no breakdown of the line itself can be directly traced to lightning.

There have been many interruptions caused by wires or sticks thrown over the lines; a few by birds, and one by a wild-cat. Once only has a pole been blown down, while once the whole superstructure of a box car was blown from a train into the wires.

In the inter-mountain region wooden poles have a life of not more than ten years; many last only five years. It has been found that salt is the best preservative for the butts of poles, but if the butt is made to last ten years the upper part of a cedar pole will check and become so brittle that its useful life is gone in that time.

The writer in 1903 constructed a pole-line for the Utah Sugar Co. from their power-house on the Bear River to the Utah Light and Railway Company's power-house at Ogden, a distance of 45 miles. The line was designed for 40 000 volts, and is operated at 28 000. It is located at the base of the Wasatch range, just above cultivated ground, but within a few hundred yards of a good county road. The location was costly as regards pole construction, but was necessary in order to avoid trees. The line consists of 40-foot cedar poles with cross-arms. The wires are spaced on a six-foot triangle. The upper cross-arm is short and the insulator is placed on alternate sides of consecutive poles. This arrangement avoids the bad practice of placing a pin on the top of a pole. The lower cross-arm is heavily braced and the cross-arms are strengthened and prevented from splitting by $\frac{1}{4}$-in. steel plates held together by carriage bolts. Poles are spaced 44 to the mile. The line wire is No. 0, soft-drawn, solid copper. The insulators are three-part Locke brown porcelain. The upper part is 11-in. diameter, and was tested to 40 000 volts. The middle part was tested to 30 000 volts, and the lower to 50 000 volts. The pin is of cast iron with a collar $3\frac{1}{2}$-in. diameter and a $\frac{3}{4}$-in. steel bolt cast into the shank. It is cemented into the insulator with neat Portland cement. The pins and insulators complete weigh 20 lb. each and cost nearly $2.00 in place on the pole. They are heavy and expensive, but they are strong and make a splendid insulator for a heavy line.

In stringing wires half a mile of wire was stretched at a time, and the writer has repeatedly seen a single insulator stand the whole strain without any trouble. There are three long spans on this line, two of 250 feet and one of 450 feet. Solid No. 0 was used for these spans, and 15 feet sag allowed. The wires were supported by three insulators at each end, set in a special iron fixture. The whole strain of the span is taken by these insulators. All corner strains are taken by single insulators and they are strong enough to stand them. The

whole line was built for mechanical strength and so far it has given no trouble. Some 30 or 40 of these insulators have been in use through the past winter on outdoor 40 000-volt air-switches and have shown no sign of failure. The insulators are not expensive to repair, as the upper part when broken can be cracked off and a new part cemented in its place; the pin and the rest of the insulator are used over again.

This pole-line cost $2000 per mile, and has probably as much steel and iron in its construction as can be used on any wooden line. The next important line in Utah will undoubtedly be entirely steel supported, for a careful comparison of costs shows that the Bear River line, just described, could have been built just as cheaply with steel towers as with poles.

The writer believes that a single line of steel towers set 500 feet apart carrying two circuits of copper wire, spaced on six-foot triangles, will be much cheaper, both in first cost and maintenance, and freer from interruption and safer for repair work than two separate wooden pole lines.

It may be argued that if a wire from any cause drops on the structure it will make a dead short circuit. It will, but the wire will be burnt off in an instant and in a properly laid out and operated plant the trouble will be located and the section isolated without delay.

It would be interesting to get figures on the cost of erection of the steel towers, assuming labor at $1.50 per day, teams at $3.50 per day, and average length of haul four miles. The writer is not in favor of using aluminum cable. It is cheaper and lighter than copper, but it lacks the strength and may be worth very much less per pound in a few years, whereas copper is not liable to depreciate much in value.

A. S. HATCH (*by letter*): On page 556 it is assumed that the steel towers act as lightning-arresters. The writer cannot agree with the statement unless the tower is grounded in permanently moist earth. In testing the street lighting circuits for grounds or opens, it is found that the towers are not generally grounded in dry weather, being grounded but a few days after a storm. As a storm usually follows dry weather, at least before the rain has had time to penetrate any distance into the ground, the towers may be fairly well insulated by the dry earth. There have been several instances where lightning has struck a tower and, following a guy-wire to the wooden stub, has splintered it in passing to earth rather than follow the tower. In one case, lightning struck a tower and puncturing the lamp insulator discharged through the circuit which was grounded in the station. This experience, together with the statement made during discussion that the steel towers were usually located on high points of ground, emphasize the importance of grounding the towers thoroughly.

Discussion on "Synchronous Motors for the Regulation of Power-Factor and Line Voltage."

F. O. Blackwell: In a large plant it is an unnecessary extravagance to figure the copper for a low power-factor when the power-factor can be made 100% by adding leading current to the lagging current caused by induction motors. Even a small lagging power-factor increases the amount of copper very greatly for any assumed regulation.

Rotary condensers are also of great advantage in permitting the pressure of a power transmission system to be regulated at the centre of distribution. It would be perfectly possible to run a power transmission system with rotary condensers in the sub-station without any communication between the sub-station and the distant power-house. The first case of the use of a rotary condenser that the speaker knows of was in a Southern cotton-mill which was equipped with about 4000 h.p. of induction motors and 3000 h.p. of generators. The pressure and the current at the generators was excessive on account of the low power-factor of the load and something had to be done to relieve the apparatus. By installing a rotary condenser of 500 apparent kilowatts capacity in the mill the pressure at the generator, if the speaker remembers correctly, was cut down about 15% and the current was reduced about 20%. The rotary condenser also greatly improved the regulation of the system and avoided the installation of a new generator in the power-house, which would have otherwise been necessary and would have cost several times as much as the rotary condenser.

A 6000 h.p. plant in India, which transmitted power 90 miles, reached the limit of its capacity. The owners decided to increase its capacity by installing a 1000-kw. rotary condenser, and they have been enabled to transmit 50% more power over their existing line, with the same regulation as they had originally with the smaller amount of power. If it had not been for the rotary condenser they would have had to construct an entirely new transmission pole-line.

It is possible not only to maintain 100% power-factor in a transmission system, but also a leading current which will boost the pressure over the reactance of the line and step-up and step-down transformers, so that you can have as high a pressure at the sub-station as at the power-house, or even a higher pressure.

Of course, if a synchronous motor can be used to do useful work it is more economical than a rotary condenser. The most efficient power-factor would be 70% leading, at which point the energy and wattless components of the current are equal. You would then get 70% of the rated capacity of the motor for work and 70% for rotary condenser action.

As Mr. Lamme has pointed out, the high-speed, steam-turbine alternator is not the cheapest machine that can be de-

signed. A speed of about one half that used in turbo-alternators avoids all extreme strains which require special materials and methods of construction and is therefore more economical in design.

W. L. WATERS: This paper is a suitable sequel to the paper which Mr. Lincoln read last year on the "Choice of Frequency for Transmission Lines." Mr. Lincoln showed that if the power-factor on a transmission line was low, the amount of power which could be transmitted over that line, with reasonable regulation, was surprisingly small, and it followed from this that the power-factor should be kept as near as possible to unity.

Mr. Lamme is not quite clear when he describes the effect on the regulation of an over-excited synchronous motor. The beneficial effect of a synchronous motor is entirely due to the leading current, which it takes from the line. The amount of leading current which a motor can take from the line is decided by two things: 1. the margin in ampere-turns, which we have on the magnets. 2. the current in amperes, which the armature can carry.

Both of these are limited by the heating of the magnets and armature, so that, if we are manufacturing a synchronous motor for regulating the pressure on the transmission line, the correct rating of that machine should be the amperes of leading current which it can take when running at a given pressure without the temperature rise of the magnets or armature exceeding 40° cent. The normal rating of the machine and the short-circuit current tell you very little as regards the value of the machine for producing leading currents. We might have a large motor capable of giving a large short-circuit current, which, at the same time, was valueless for pressure regulation on account of the fact that we could not over-excite the magnets because their temperature rise was already high.

As the rating of the motor, as above suggested, is entirely limited by temperature, the force of Mr. Lamme's remark that turbo-alternators are unsuitable for this work becomes very plain. Those who have had experience with these very high-speed machines know that the great difficulty in designing them is to obtain low temperature rises, especially on the field magnets. The other objection to high-speed machines, that they are less reliable in operation, is not of much importance in the case where these motors are used exclusively for regulation of the power-factor. So considering only the question of temperature rise, probably the most economical machine would be one in which the output was about 250 kw. per pole in a 25-cycle machine and about 125 kw. per pole in the 60 cycle.

Mr. Lamme calls attention to the inherent regulating power of a synchronous motor. This effect certainly exists, but under ordinary conditions it is unimportant, and the main

use for the synchronous motor as a pressure regulator would be as a hand-operated regulator. In this respect, Mr. Lamme's statement that "the motor should preferably be one in which the magnetic circuit is not highly saturated," is incorrect, because a motor which had saturated magnets would have a much greater inherent regulating capacity than one in which the magnets were unsaturated; if the motor were infinitely large and perfectly saturated its inherent regulating capacity would be perfect. This statement, as regards unsaturated field magnets, is also incorrect if we consider the motor as being hand regulated, because the effect is one of ampere-turns and not of magnetic flux; that is, assuming the magnetic leakage is not excessive.

The effect of copper dampers on the pole pieces is only a time effect. They slightly delay the effect of a sudden rush of leading or lagging current, but in any case this effect only applies to the inherent regulating automatic action of the machine, so that for all practical purposes the effect of dampers on the pole pieces can be neglected, except as regards their effect on the hunting of the system. In regard to this hunting, Mr. Lamme's statement that squirrel-cage induction motors are more powerful as dampers than motors with coil-wound secondaries and collector rings, is not correct. The damping effect of an induction motor is greater the lower the resistance of the secondary. If we consider modern commercial induction motors, that is, motors capable of starting under full load without taking excessive current, then the resistance of a squirrel-cage secondary is about five or six times that of a coil-wound secondary with short-circuiting device, and in consequence the damping effect of the squirrel-cage armature would be proportionately less.

The question of the use of a synchronous motor running light as a pressure regulator is entirely a commercial question, and the advisability of its use in any particular case must be decided by the question whether the cost of this motor is more than compensated for by the increased output obtained from the line.

H. B. GEAR: This question has been discussed thus far with reference to the compensation of systems where the low power-factor was due to lagging current.

In a system operating at 40 000 volts with 200 miles of line the conditions may be reversed, the low power-factor being due to the component of leading current caused by the charging of the line. In such a system the kilovolt-amperes required to charge the lines amount to about 1800. It therefore requires a load of 3000 kilovolt-amperes at 80% lagging to bring the power-factor of this system up to 100%.

The use of a synchronous motor in compensating for a low power-factor on such a system would therefore be limited to the compensation of leading current up to the point where

the load of induction motors reached 3000 kilovolt-amperes. Under certain conditions it might therefore be possible to install a synchronous motor of relatively small capacity, using it during the light-load period to compensate for leading current and during the heavy-load period to compensate for lagging current.

W. B. JACKSON: All of us must appreciate that this paper upon synchronous motors is an excellent and timely one. Although the question as to the proper use of synchronous apparatus has been recognized as quite important for a number of years, yet it is assuming much greater importance as the great transmission systems are becoming more common.

One phase of the use of synchronous motors has not been touched upon in the paper. In the construction of our power transmission plants receiving their power from water, it is not unusual for the hydroelectric portion of the plant to be developed to a point far beyond the minimum capacity of the water. Consequently an auxiliary steam plant is installed to assist during low-water periods. Under such conditions there is often an excellent possibility for the plant to be so designed that the generators in the steam department may be used for balancing motors during the time of heavy load upon the hydraulic plant. It is readily appreciated that at times of low water or of serious back-water conditions the transmission department of the system will be lightly loaded and that, therefore, ample electrical capacity will be at hand to take care of a lower power-factor without difficulty so far as the transmission department is concerned, and at the same time we have the steam auxiliary in operation which will act as the balancing factor upon the system.

Why should not any such plant be so arranged that the engines and generators can be readily disconnected during the times when balancing by synchronous motors is desirable? In other words, when we have the transmission side of the system loaded to its utmost capacity? There is no reason why the possibilities of our auxiliary generator as a balancing motor should be lost sight of simply because it is normally connected to an engine. It is not at all difficult to arrange to disconnect these alternators from the engines and use them for balancing machines, thus making a double use of the apparatus that is installed for the auxiliary plant.

The reversible use of alternating-current generators in transmission plants, either as generators or motors, as the occasion may require, is not uncommon, but the reversible use of the machines as generator or balancing device is quite a different question.

Reference is made in the paper to the possibility of so installing synchronous motors upon the circuit that they may be caused to hold the pressure at the end of the line as high or even higher than that of the generators. There are several

plants where such use has been made of synchronous motors for years past; in fact, there are two plants that the speaker knows of where it has been customary to operate generators at approximately the same pressure as at the distributing end of the line, these being plants where a large part of the capacity of the plant was supplied to synchronous motors, and where it was possible to get into communication with the several synchronous motor installations without difficulty from the power-house. It would probably not be difficult to find plants where it would be practically impossible to operate at all were the synchronous motors now installed replaced by induction motors.

F. A. C. PERRINE: The suggestion Mr. Jackson has just made is a very important one, and we all would perhaps be interested to learn that it has been quite extensively used in some Western plants, and in connection with reserve steam machinery for compensating for large leading current on the line, and also automatic compounding of the synchronous motors. For example, in the steam station of the Oakland Transit Company, Oakland, California, supplied by the Old Bay Counties system, transmission of 140 miles, they were compelled to have a steam reserve, on account of fluctuations in pressure. F. H. Baum, one of our members, was called on to determine what could be done, as on account of the very heavy leading current when the load was light the pressure went up, and when the load was heavy the pressure went down. The fluctuations of the pressure were of a serious nature.

Mr. Baum compounded the exciter for the synchronous motors by the direct current, using an extra winding on the exciter, and he arranged this compounding so as to maintain a constant pressure on the system and almost a constant power-factor automatically without any hand regulation of the machine or the synchronous motors. He found, furthermore, by examination with an oscillograph, that Mr. Lamme has apparently not made himself understood on page 552, as he says it is not possible by means of the synchronous motor to correct errors in wave form. In the latter part he says: "such currents will in general be of higher frequency than the fundamental wave of the system, and the synchronous motor obviously could not correct for them, unless it impressed upon the system opposite waves of the same frequency. This would mean a synchronous motor with a different wave form from that of the system." That is exactly what the synchronous motor does at the end of a long line; at the end of a long line the initial wave form is very seriously distorted, and the synchronous motor having a wave form similar to the generator corrects for the variation induced at end of the line.

Again, in some of the mining plants supplied from long-distance transmission lines where the charge has been made on the basis of the maximum current, they have found it advan-

tageous to install synchronous condensers for maintaining high power-factor, the plant being operated by induction motors, the synchronous condenser being used as a reserve steam generator when, by reason of any accident, the power from the transmission line was interrupted.

As regards small plants where it is necessary to maintain a constant power-factor—and the power-factor is already reasonably high, due to the use of lighting load entirely—the synchronous motor as a regulator can be conveniently used, especially where a combined railroad and lighting load are operated from the same generator, and this again, by compounding the synchronous motor through its exciter from the direct-current end of the system. And again, this is used in connection with the steam-driven alternator auxiliary; that is, where a large alternating-current generator is employed during periods of light load, that load can be carried from a separate steam-engine of lower capacity driving an alternating-current generator. When the load rises beyond the capacity of the small engine the latter can be cut off and the load carried from the large alternator through the synchronous motor, the latter being compounded through the direct-current side and thus the power-factor maintained. This does away with the greatest objection to the installation of synchronous motors; the use of the synchronous motor gives the operator control of the whole system.

The matter of cost as presented by Mr. Lamme is surprising; not because he states there is a certain speed at which we find a minimum cost, but due to his statement that the cost of the synchronous converter will be from 60 to 80 per cent. of the cost of an ordinary-speed generator. If we take a generator having about 100 revolutions per minute, cost will be about ten dollars a kilowatt, while high-speed machines recently sold for four dollars a kilowatt. And this shows, furthermore, that the use of the synchronous motor as a condenser is about as cheap a regulating machine as can very well be obtained. It is a question whether in large sizes there can be built any hand-regulating induction regulators that will cost much less than four dollars a kilowatt, at which to-day these large high-speed machines are actually being sold, and that makes a minimum cost of a high-speed machine about 40 per cent. of the cost of the ordinary-type machine, rather than 60 per cent. The general question is an exceedingly important one, taken in conjunction with the fact that it is possible by the use of these synchronous condensers, especially when connected with direct-current machines, to automatically compound; the same automatic compound may be produced through the exciter by means of the Tirrell regulator or some other regulator of this form. And when we get away from the difficulty and the inaccuracy of hand regulation, we have overcome the most serious objection that has been raised in any of the discussions on the employment of the synchronous condenser.

F. O. BLACKWELL: In connection with what Dr. Perrine has just said, the speaker would say that it is possible to put an automatic field regulator on a rotary condenser which will make it maintain constant pressure in the sub-station notwithstanding variations in speed and pressure in the power-house. To carry this idea still further, a fly-wheel can be added to the rotary condenser which will steady the plant by absorbing and giving out energy when the load fluctuates. This has been done in Germany on a considerable scale where large hoists are operated by motor-generator sets with fly-wheels. The steam-turbine alternator is well adapted to be used as a rotary condenser where steam power is auxiliary to a long-distance transmission water-power plant. Its fly-wheel capacity is large and the friction of a steam-turbine, particularly if it is mounted on a vertical shaft, is extremely small.

RALPH D. MERSHON: The speaker wishes to take issue with Mr. Waters on his statement that Mr. Lamme has overestimated the value of the inherent regulation of the motor. Even if the regulation of pressure is, as Mr. Waters says, a matter of hand regulation, still the measure of effectiveness of this hand regulation is the extreme regulation possible, the regulation from full load to no load. The less the extreme variation is, the better the regulation, whether it be manual or automatic. Mr. Lamme has brought out the conditions in the design of the synchronous motor that are necessary for such regulation, and it is the opinion of the speaker that he has not laid any too much stress on it.

The paper by Mr. Lincoln to which Mr. Waters also refers stated the limitations and the amount of power that could be transmitted over a line at different frequencies with a given limitation in the amount of drop. He took the drop at 20 per cent. Now if you take a given drop as the limitation, then Mr. Lamme's contention is an extremely interesting and important one.

The *extreme regulation* of any system; that is, its regulation from full load to no load, is a measure of its regulation for any change of load, since the change of pressure for any change of load, large or small, is proportional to the extreme regulation. Therefore, whether the regulation of a system be automatic or manual, the extreme regulation is of importance. The extreme regulation may or may not be identical with the total drop in the system.

In a circuit feeding its load direct without the aid of corrective synchronous motors, the extreme regulation and the total drop are identical. Hence the regulation; that is, the variation of the delivered pressure varies as the load varies, is measured by the total drop. But if synchronous motors be used to control the power-factor the total drop is not necessarily the same as the extreme regulation and therefore not necessarily a measure of the regulation. Whether or not it is a measure

depends upon the characteristics of the motors used. If the motors have in them, when delivering a leading current to the system (= a lagging current in the motors themselves) a drop equal to that of the transmission, then the extreme regulation will be just equal to the drop so that the total drop is a measure of the regulation. If the drop in the motors when delivering leading current is greater than that of the transmission, then the extreme regulation of the system will be greater than the total drop of the transmission and the regulation worse than the total drop would indicate. If the drop in the synchronous motors is less than that of the transmission, then the extreme regulation of the system will be less than the total drop in the transmission and the regulation better than the total drop would indicate.

Since, with a given drop, in a long transmission having a lagging power-factor, a limit is soon reached in the amount of power which can be transmitted, it is desirable in long transmissions to use corrective synchronous motors. The use of such motors is also advisable from the fact that by reducing the transmission current they reduce the transmission loss. From what has been said it is clear that the regulation of such a system will be largely dependent upon the regulating qualities which the corrective motors have when a lagging current is being drawn from them. The subject of the regulation of such motors under such conditions is therefore of very considerable importance, and Mr. Lamme has, in the opinion of the speaker, rightly laid great stress upon it.

S. B. STORER: Mr. Waters has taken exception to Mr. Lamme's reference to the use of the squirrel-cage induction motor. The speaker is more inclined to agree with Mr. Lamme than with Mr. Waters, as the resistance of the squirrel-cage winding would seem to be considerably less than that indicated by Mr. Waters' remarks. Mr. Waters says that in this form of secondary there is from six to seven times the resistance of that of the armature type of induction motor secondary. If that is the case then the squirrel-cage winding would drop below synchronous speed from six to seven times as much as the other type of winding. General practice does not show this to be true.

On a large motor with the squirrel-cage secondary the regulation in speed is two to four per cent., and if the resistance of that secondary were six or seven times the resistance of the motor having the regular armature type secondary winding then the slip of the latter would be one-sixth as much, or only a fraction of one per cent. General practice does not show this to be true either.

CHAS. F. SCOTT: This subject, involving as it does synchronous apparatus for adjustment of regulation and power-factor, is one which seems more or less confused. In considering questions of this kind the speaker has a method of

analysis which is quite simple and straightforward. It involves a physical rather than a mathematical analysis of these problems, and it may be well to give it here.

In an alternating-current system one may consider that two things are being generated; power and electromotive force. The system receives its power through the shafts of its generators, either from water-wheels or engines (for convenience we shall simply refer to engines). The system receives its electromotive force through the magnetic field produced by the field magnets of the generator. The greater the field strength the greater also is the electromotive force. The field magnets for supplying the electromotive force correspond in a way, therefore, to the engines which supply power.

A power-house may contain two similar outfits, both driven by similar engines and supplying equal power to the system. Furthermore, both of the generators supply electromotive force and have field magnets and equal field magnetizing currents and supply equal electromotive forces to the system. If the two outfits are running in parallel and the power be shut off from one of the engines, then the system will receive power from one outfit, but electromotive force from both. The drop in electromotive force on change of load will not be determined by the joint action of a single machine but of the two machines. Therefore the regulation will be much closer with the two generators in multiple and will be essentially the same whether power is received from one engine or from two.

If one of the machines be transferred from the power-house to a distant sub-station there remains the same capacity for generating the electromotive force as there was when the two machines were close together. There is a difference, however, in that one of the generators is now located at the point of distribution so that it is a generator of electromotive force close to the point of distribution without interference of line losses in the circuit from the power-house. There is thus seen to be a close similarity in the action of two generators running side by side in parallel and one generator operating a synchronous motor at a distant point in so far as the generation of electromotive force is concerned.

In Mr. Lamme's paper it is shown that the better the regulating characteristics of the machine, or in other words, the greater the effectiveness of its field, the more effective it is for its purposes. If we follow through the paper and note the different characteristics desirable in the machine, and if we further consider the various points brought out in the discussion we shall find that they may all be comprehended in a clear and definite way by simply assuming that we have transferred a generator from the power-house to a distant point upon the line where the electromotive force is needed and where it may be more effectively generated than in the power-house. There is nothing mysterious in the fact that a syn-

chronous motor is used. If it were not for the line losses it would be better to generate all the electromotive force in the power-house in the power generator. In general it is cheaper and more effective to provide generators with the desired field strength and regulating qualities rather than to provide other synchronous machines for generating the electromotive force. The reason that it is sometimes preferable to use the auxiliary synchronous machine lies in the fact that it may be placed near the load, and therefore generate the electromotive force where it is needed.

In considering the second division of the paper, namely, that relating to the control of the power-factor of the circuit, we may follow the same line of reasoning. In our electric system we may consider that we are generating currents of two kinds; one a current in phase with the electromotive force; the other a wattless current having a phase relation of 90° to the former. Ordinarily these two currents are produced in the same armature and combine to give a resultant at some intermediate angle dependent upon the relative values of the two currents, upon which in turn the power-factor is dependent.

If, again, we consider that a power-house has two generators, we know that the two could supply equal power and equal current at the same power-factor. On the other hand, adjustments could be made so that one of the generators will supply all of the working current of the circuit at 100% power-factor while the other supplies the wattless current. In this case the engine of the second generator would do no work and it might be disconnected from its generator. In general, however, as pointed out in the original paper, this is not a good thing to do, because the two kinds of current can be generated in one armature more economically than in two armatures. For example, if the requirements of the circuit are that there be 70 amperes of each kind of current, then each armature must develop 70 amperes. The resultant of the current, however, is 100 amperes, so that one machine having a capacity of 100 amperes could give the same effective output as two machines each of 70 amperes. This shows the fallacy of the suggestion sometimes made, that a machine running idle should be installed in a power-house for supplying wattless current. It is much more economical to install a generator of sufficient size for supplying the necessary current. There may of course be exceptional conditions, where the generator is already installed, in which the best arrangement under the circumstances may be the installation of an auxiliary machine. When, however, there is a transmission line, it is obviously desirable to carry simply the power current for transmitting the necessary energy and not to impose the wattless current upon the transmission line. The wattless current is objectionable in the line for two reasons; it increases the total current to be carried, and it also very considerably increases

the drop in pressure in the line. If therefore the wattless current could be generated at the point where it is needed; that is, at the point of distribution, the transmission line will be very greatly relieved and its capacity increased. In a sense therefore we are simply relieving the transmission line from carrying wattless current and putting the generator for producing this current at the sub-station near the load.

If the various points taken up in the original paper relating to the desirable characteristics of the machine and also the points brought out in the discussion are considered, we shall find that the various requirements are quite rational and that the purpose is simply to generate two currents, one a power current at the power-house and the other a wattless current at the sub-station.

The synchronous machine at the sub-station can therefore accomplish both of the desired results. Namely, by supplying electromotive force it can facilitate the pressure regulation, and by supplying wattless current it can relieve the transmission line.

Many of the objections to synchronous motors for general use do not apply to the use of synchronous machines for the foregoing purposes. It is the speaker's opinion—which he thinks is coming to be the general opinion also—that a considerable number of synchronous motors of various sizes, particularly motors of small size, scattered over a system under the control of various operators, does not constitute a satisfactory working condition. In a theoretical way it may be all right and matters may run smoothly for a time, but when an accident occurs at one place trouble is very likely to occur in many places, resulting in interruption to service.

The induction motor is the simple one for the general distribution of power. In those cases where the magnetizing or wattless current taken by it cannot well be provided by the generating and transmission system, as is sometimes the case in long-distance lines, this current may be supplied by large synchronous machines running in sub-stations. When large machines are operated in stations so that the machines themselves are few and the operators are intelligent and skilled men, then objections to the synchronous operations are reduced to a minimum and the operation is comparable to the ordinary synchronous converter sub-station which has demonstrated itself to be quite practicable.

Even this statement does not imply that all large motors should be synchronous motors. The large induction motor has a relatively high power-factor, and the operating simplicity of this motor and the characteristics of its speed-torque curve make it in many cases much preferable to the synchronous motor.

The use of one machine which may sometimes be driven by an engine at the sub-station and at other times as a pressure regu-

lator, has been mentioned once or twice in the discussion. A case came to the speaker's attention some time ago in which such an arrangement seemed to be advisable from the standpoint of the customer. The customer was intending to purchase a considerable amount of power from a transmission system, and his proposed contract was based on power furnished at a certain power-factor. If the power-factor was lower the rate was to be increased, and if the power-factor was higher the rate was to be decreased, and the immediate problem was whether the increase of power-factor which could be secured through the use of an auxiliary synchronous machine would make it worth while to make arrangements so that the machine could run part of the time as an idle synchronous motor and part of the time as a generator driven by an engine. It was proposed to install the engine for a relay in cases of emergency. The synchronous machine would therefore be so arranged that it could be used as a generator of wattless current for raising the power-factor under ordinary conditions and as a power generator in cases of interruption to the outside service.

The speaker is inclined to think that this general method of operation is applicable to long distances and larger powers, and that it will not be found expedient to introduce it in smaller plants on account of the extra complications which may more than compensate for the advantages and expense involved.

F. A. C. PERRINE: Will Mr. Scott please say if it is a correct corollary to the first part of his remarks to state that in case of long-distance transmission plant generating at about five cents per kilowatt-hour, what is a fair figure for such plants transmitting to long distances? Would it be correct to state that it were better to use a steam-driven generator for regulating the pressure—power from the steam-driven generator costing about one cent per kilowatt hour—or a synchronous motor?

CHAS. F. SCOTT: Of course special cases will admit of almost anything, but the speaker did not have in mind the supply of mechanical energy at the sub-station simply to assist in either the regulation of current or pressure. That would not be necessary in general, unless the speed were the real factor which needs correction and regulation. There may be cases in which the fluctuations in load would cause fluctuations of speed in a water-wheel that a steam-engine would be a good adjunct as a speed regulator. But the speaker has not had in mind the introduction of power from a steam-engine simply to assist the control of the pressure or the current.

J. S. PECK: There is an interesting bit of history connected with this system of adjusting power-factor by means of a synchronous motor. About 1890, Mr. Lamme did a considerable amount of experimental work along this line, with a view of determining the extent to which the pressure of a generator could be varied by changing the field strength of a synchronous

motor which was supplied from it. Experiments were carried on for a year or two in order to determine definitely what could be done, and in 1893 an application was made for a patent covering this system of operation. The patent was, however, refused by the Patent Examiner, on the ground that a current could not lead the pressure which produced it. About one year later, a patent was granted to another engineer covering substantially the same arrangement. The matter was called to the attention of the Patent Office officials, and after a time Mr. Lamme's original patent application was granted.

A perusal of this Patent Specification shows that as early as 1893 Mr. Lamme had a clear conception of the action of synchronous apparatus in controlling the power-factor and pressure of an alternating-current system, as well as the reasons why the various results were obtained. Although the specification was written more than ten years ago, practically all the essential points which have been brought up to-day were covered therein.

Dr. Perrine expresses surprise at the fact that Mr. Lamme says that the cost of a synchronous motor regulator will be from 60% to 80% of the cost of an alternating-current generator of the same capacity and of ordinary speeds. The relative costs given by Mr. Lamme are based on equal currents on short circuit. Mr. Lamme calls attention to the fact that high-speed turbo-generators, of which the cost per kilowatt is comparatively low, are usually designed to give less current on short circuit than generators operated at the usual speeds. Regarding the superior regulating action of the motor supplied with dampers on the poles, Mr. Lamme refers to momentary effects only.

S. B. Storer: In connection with the use of synchronous regulators, one point has not been referred to; that is, the effect in case of a short circuit in a very large system where synchronous regulators are used for maintaining a very high power-factor. The present tendency is to limit the short-circuit of all large plants to as small an amount as possible consistent with fair regulation. It seems to the speaker that with the general use of these synchronous regulators in sub-stations the short-circuit current which might be obtained at a given point would be so much larger than where induction regulators are used, that it will be very difficult to overcome and will prove an objection to their use.

H. W. Buck (*by letter*): Mr. Lamme's paper shows the important functions which a synchronous motor can perform upon a power transmission system. The writer should be inclined to go further and say that synchronous machinery of some kind is a necessity on almost every power system, where alternating current is distributed, as a compensator for lagging currents.

If the power is used by a large number of small consumers,

as is frequently the condition, the majority of these users will install induction motors, both on account of the simplicity of the type, and also because their conditions of operation require frequent stopping and starting and high torque on starting, which conditions exclude the use of motors of the synchronous type. While it may be argued that large modern induction motors with small air-gaps have high power-factors at full load, many of the motors on the average power system may not be very large, and they are seldom running at full load. Their power-factors at fractional loads will be much less. Over the entire system there will be perhaps hundreds of induction motors, some of them running light, many of them running at about half load or less, and only a few operating at the exact load at which the high guaranteed power-factor can be obtained.

The result of this condition is, in the experience of the writer, that the average power-factor on such circuits at normal loads is not over 70%, and frequently it falls as low as 60%. Such a condition is, of course, highly objectionable. This increased current, which earns no revenue but which simply causes heating and excessive "drops" all along the line, will so enlarge the investment in generating and transmitting apparatus that the profits from the business may be seriously impaired.

If the electrostatic capacity of the transmission system is high, compared with the amount of power transmitted, as is the condition in some very long-distance high-pressure systems, the charging current of the line may offset the magnetizing currents of the induction motors and no other source of leading current is required. In a distribution such as that from Niagara to Buffalo, however, where the transmission pressure is comparatively low, and the induction motor load very large, the corrective effect of the line-charging current is negligible, and some source of leading current is essential.

Condensers as now constructed are expensive and bulky, and are practically out of the question for commercial frequencies. Synchronous apparatus, then, is the only possible source of the required leading current, and their installation should be insisted upon by the distributing company in every case where the users' conditions will permit. Arrangements can usually be made with the customer to operate such motors with leading current; if not, they can certainly be operated at unity power-factor, so at least they will not add any *lagging* current to the system.

Synchronous converters will of course answer the same purpose, but their armatures will not allow as much leading current as a synchronous motor, on account of heating. It may be of interest to note here that if the single-phase railway becomes the standard system of the future, the railway synchronous converters now so commonly used on power systems for phase control, will disappear, and the lagging currents in the single-phase motors will be added. Synchronous motors as sources of leading current will then be needed all the more.

There is a general feeling that a synchronous motor cannot be used in any installation where torque is required to bring the plant up to speed, and that in general a synchronous motor is a very difficult machine to start. Synchronous motors are now designed with a considerable starting torque, and with such characteristics that they will come up to synchronism very promptly without taking more than 25% in excess of full-load current. A suitable starting device is of course required. If very high starting torque is required, friction-clutches can be installed between the motor shaft and the work, which can be thrown in after the motor is up to speed with its field on, when the full torque can be obtained. There is a 500 h.p. synchronous motor on the Buffalo system, which is started in this way, with a clutch, and the operation is perfectly satisfactory. The clutch surface is well greased and thrown in gradually, and the entire plant, which is a flour-mill with all its multiplicity of belts, counter-shafting, grinders and other machinery, is brought up to full speed in a very short time without exceeding full-load current.

Another important function of synchronous motors on a system (aside from their ability to steady the pressure as mentioned by Mr. Lamme) lies in the fact that they act to steady the frequency. Since the synchronous motors are rigidly connected to the power-house generators by an electromagnetic coupling, their fly-wheel effect is added directly to the generator fly-wheel effect, and consequently they aid the generating units in the maintenance of constant speed. Induction motors cannot so operate. Their connection with the generators on the system is loose, so to speak, there being a lost motion lying between the positive slip of the motor, operating as a motor, and the negative slip which must exist in the motor before its fly-wheel effect can react on a falling generator speed.

The above stated advantages of the synchronous apparatus assume that ideal conditions exist on the system for the effective use of the characteristics of this type of machine. There are, however, circumstances under which the theoretical benefits cannot be realized. One is in the case where pulsations are impressed upon the system such as almost always result where the prime mover is a reciprocating engine. These pulsations, however small they may be, under certain conditions seem to disturb the balance of the synchronous machine, and it is practically impossible to obtain any satisfactory phase control by field adjustment, on account of hunting or other cumulative action.

Another troublesome condition is met where a synchronous motor is installed on a system of large electrostatic capacity when the counter e.m.f. wave of the synchronous machine is widely different from that impressed by the generators. Here a large current may flow in the motor armature, the frequency of which will be that of the harmonic which has distorted the

motor's counter e.m.f. wave. This current will flow back into the line as a charging current, and the motor may have more than full-load current in its armature, regardless of load and field adjustment, and phase control is impracticable.

T. J. JOHNSTON (*by letter*): Mr. Lamme's paper on the use of synchronous motors for regulation of power-factor in transmission lines is most timely. Mr. Lamme does not suggest any means of varying the reactive effect of the motor to compensate for variations on the line; it is manifest that fixed conditions do not prevail upon a transmission line, where at one time numbers of converters are in use, and at other times some or all are shut down; or where many induction motors are used as a day load and at night the principal service is incandescent lighting, or lighting with constant-current transformers. Under such conditions the power-factor of the line as a whole changes, and sometimes quite rapidly, so that manual regulation of a resistance in the field-circuit of the motor does not entirely fit the situation. The proposal which the writer made as long ago as 1901 to solve this difficulty was separately to excite the motor and feed the armature of the exciter (which should be on the same shaft with the motor armature) with alternating current from the main line; a connection being made from one armature to the other in such manner that the polarities induced in the exciter armature by the main alternating current are somewhat in advance of those due to its rotation across the field-magnet poles, and of the same sign.

With this arrangement when the main line current leads, the magnetic maxima in the exciter armature pull apart and the resultant magnetization is decreased so that the pressure and the exciter current drop, thus lowering the field magnetism of the motor; conversely, when the main line current lags, or leads to a less extent, the magnetic maxima approach each other, and the resultant pressure of the exciter is raised. This arrangement gives with a magnetic circuit having a good deal of iron a practically incremental regulation of the power-factor. Its resemblance to Mr. Rice's method of regulating the pressure of an alternating generator will of course be observed; the difference, however, is that in case of a generator the power-factor is not regulated at all, but the inductive reactance is compensated by an increase of the terminal pressure of the generator, and consequently of its output; whereas in the scheme now proposed the pressure differences are substantially unaffected.

It was a surprise to learn that motors of such large output were contemplated by Mr. Lamme for regulation alone, and perhaps it will be a surprise to many engineers more familiar with the problem. The proposed speed of 3600 rev. per min. seems prohibitive. An inductor alternator of 3000 rev. per min. within the writer's knowledge gave enormous trouble in bal-

ancing, and when at its best could be heard half a mile; the diameter of the inductor was not substantially different from that of a synchronous motor of the sizes proposed.

Not much could be accomplished by the use at only one end of the line of the regulation here suggested. Theoretically the compensation for inductive or capacity reactance must be infinitely distributed; and following the principles laid down in Chapter XII. of Dr. Steinmetz's *Alternating Current Phenomena*, it will be necessary to install these regulators at a number of points on any long transmission line; of course, under such circumstances the sizes contemplated could be reduced. For example, in those transmission lines from which branch several side circuits to different points, a regulator might be installed at or near each junction of the main line and a branch, to take care of the power-factor regulation. The power-factors at different points on a long line often differ appreciably.

The synchronous converter is not well adapted for this purpose, not only for the reasons pointed out by Mr. Lamme, but because of the danger of reversal with such a machine, causing it to operate from the continuous-current side if the inductive compensation is carried too far. This would necessitate special arrangements to prevent the converter racing, and render it difficult to operate in multiple with others; laying aside the question of hunting when the continuous-current load changes.

There ought to be a future for this form of regulator, not only on transmission lines as ordinarily understood, but in alternating-current railway practice. With proper design and output proportioned to the work, there seems no reason why these comparatively simple machines might not be installed and require only a minimum of attention.

Discussion on "Contribution to the Theory of the Regulation of Alternators."

H. M. Hobart and Franklin Punga (*by letter*): The authors agree with Mr. C. A. Adams, Jr., that their theory is suitable primarily for the designing engineer, and starting from this basis, all the factors involved in the armature reaction have been calculated. But to make this theory applicable as a check on specified regulation it is not necessary to invent an altogether new and different theory, as all the factors examined in the one case also exert their influence in the other case. It is, however, very desirable that further experimental investigations should be made bearing on the nature and magnitude of those components the predetermination of which is still inexact. These components are:

The self-induction of the armature itself;

The leakage-factor of the field-spools;

The saturation curve.

The self-induction of the armature itself may be experimentally determined in two ways, and the possibilities of having two different methods for its determination should give a much desired additional check. The one way is to measure the self-induction of the winding, and at the same time, by means of an exploring coil, the component crossing the air-gap; the difference between the two fluxes thus determined would give the stray flux in the slots and associated with the free length of the winding. A second way of measuring the pure self-induction is by means of the short-circuit curve, which contains the effect of self-induction and of demagnetizing reaction. As the demagnetizing ampere-turns can be calculated fairly accurately—even for air-gaps not at all uniform—this would allow of a determination of the remaining part, *i.e.*, of the pure self-induction.

The measurement of the leakage-factor and the plotting of the saturation curve involve nothing new. The measurement of the armature reaction at full load and zero power-factor would serve as a further check on the exactness of the calculation.

It is quite true, as Mr. Behrend points out, that the shape of the saturation curve may—besides the ohmic drop and the ratio pole-arc to pole-pitch—change the relation between regulation at unity power-factor and at zero power-factor. A machine with large air-gap and low field saturation may have the same regulation at zero power-factor as another machine with small air-gap and high field saturation, but the regulation at unity power-factor will most probably be considerably better in the first machine; or if the regulation at unity power-factor is the same for both machines—ohmic drop and ratio of pole-arc to pole-pitch and all other important factors being the same—the machine with the greatest part of its field ampere-turns required for the saturation of the iron will have

the lowest regulation at zero power-factor. Such extremes as 5% on purely inductive load and 10% on non-inductive load, as mentioned by Behrend, are impossible, unless the ohmic drop is from 5% to 10%. This point possesses considerable interest as regards the design of alternators, but not as regards the reliability or unreliability of the method under consideration.

We find the statements of Mr. W. L. Waters to be somewhat confusing and are obliged to differ with him with respect to most of his criticisms. From his "theoretical conclusions" Mr. Waters maintains that the lines which cross the air-gap should also be considered as belonging to the pure self-induction, but his practical experience leads him to think that such a step would show a wide discrepancy between observed and calculated points; and so it would. Hence the fault must lie in Mr. Waters' theoretical conclusions.

The authors were not aware of Mr. Adams' publication in the *Harvard Engineering Journal* (Nov., 1903), but they have never intended to claim any priority for this method of calculating the influence of the leakage, as Rothert and many

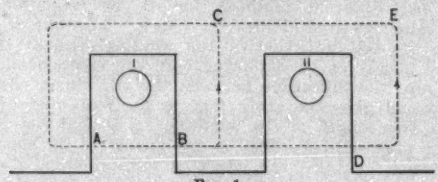

FIG. 1.

others had already employed it, and the authors considered it as an already well-known method. To whom the priority in this case belongs the authors are not prepared to state. A complete investigation of the priority in such a case is a very considerable undertaking. It possesses but little interest to most engineers and might with advantage rather be left to books than to papers, though, on the other hand, acknowledgement of priority should preferably be made when readily practicable and not involving an exhaustive historical research. It is, however, surely beyond the scope of a paper dealing with a problem in practical engineering, to carry this matter so far as Mr. V. Karapetoff would require, in acknowledging the "breadth-factor" to Professor Arnold as the term has long been a familiar one in the sense employed by us.

Mr. Karapetoff has confined his criticism to stating that each component of the complete theory has already been used by other authors. Even if this were the case the usefulness of the theory as a whole is in nowise less; the authors are nevertheless of the opinion that there are a few points which have

been neglected in all previous theories relating to this subject. These, of course, would be the essential parts, so far as priority is concerned, but they need by no means be the most important parts of the theory as a useful whole. The chief point is that the armature stray lines crossing the air-gap cannot be defined as pure self-induction, that they therefore cannot be treated like an ordinary vector, that they only increase the angle of lag between mid-pole position and centre of armature ampere-turns, and that they have no effect on the internal pressure.

Mr. Karapetoff asserts that no account has been taken of the mutual induction of the coils. This is another essential point in which we claim priority, for the mutual induction has been taken into account in our method. Thus all these lines crossing the air-gap and defined by many authors as belonging to the self-induction, are produced by the sum of all the armature conductors. It is exactly this mutual induction which causes the stray flux (Path II), to have a nearly constant position with reference to the main flux in polyphase generators.

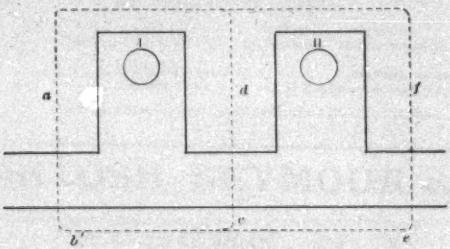

FIG. 2.

For the pure self-induction (Path I), the mutual induction has been neglected, as it is very easy to see that it can never amount to more than 5% or 10% of the total pure self-induction, and as this latter is only a small component of the total armature reaction, it is evident that taking into account this mutual induction would be an absurd refinement.

Conductor I carries current, while its mutual inductance toward conductor II has to be determined. It is clear that the stray flux has to follow the path *A B C* (Fig. 1), thus constituting self-induction, or the path *A B D E*, thus constituting mutual induction with respect to conductor II.

The amount of the flux following these two paths will be inversely proportional to the resistance along *B C* or *B D*, and as in the one case, the flux has to pass along through the tooth, in the other case, through a large air gap—width of slot—the flux following the path *B D* will be far smaller in

amount than the flux following the path *B C*. As in modern generators there are seldom less than two or three slots per pole per phase, the percentage of the mutual self-induction will be at least two or three times smaller than in the above case, so that it can easily be understood that the mutual induction component of the pure self-induction is only a few per cent.—say 1% to 5%—of the pure self-induction.

Quite different is the case with the lines emerging from the armature and crossing the air-gap (Path II). The lines following path *a b c d* (Fig. 2) have approximately the same resistance in the magnetic circuit as the lines following path *a b e f* and constituting the mutual induction.

This is one of the reasons leading the authors to split the armature stray flux into three classes; and the mutual induction in Path II has been regarded as an important factor which has been taken into account in no other theory.

It would thus appear that Mr. Karapetoff's criticism has chiefly related to deploring the absence of the very factor which is for the first time provided for in the authors' method.

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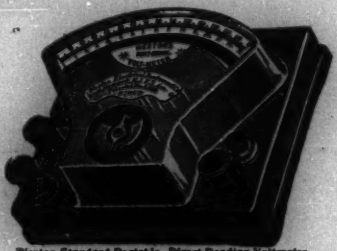

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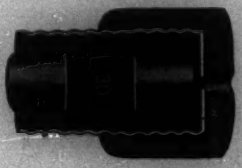

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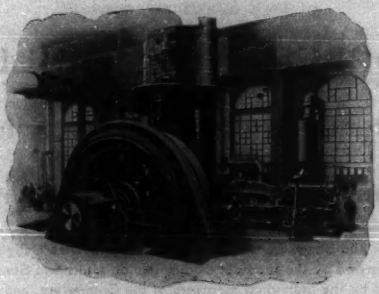

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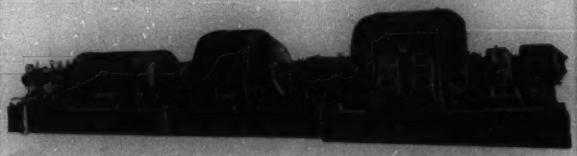

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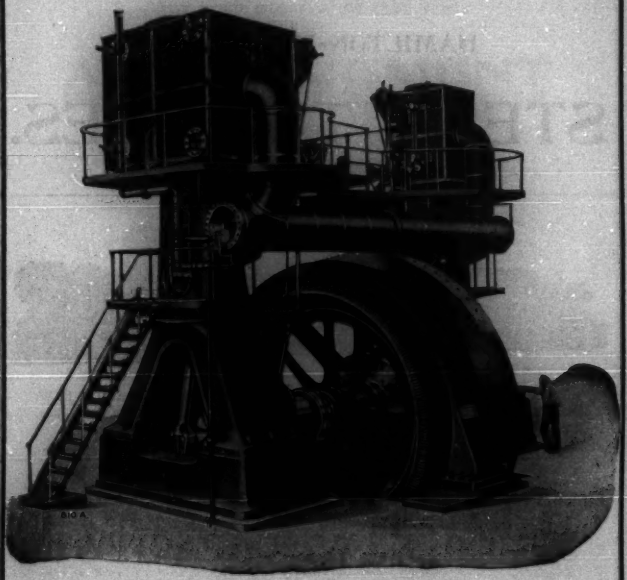

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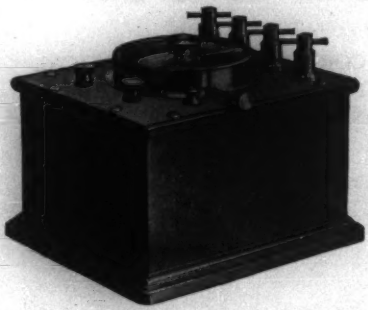

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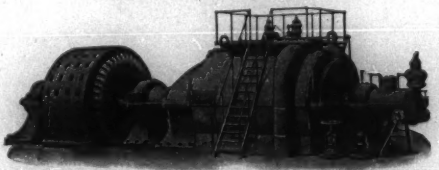

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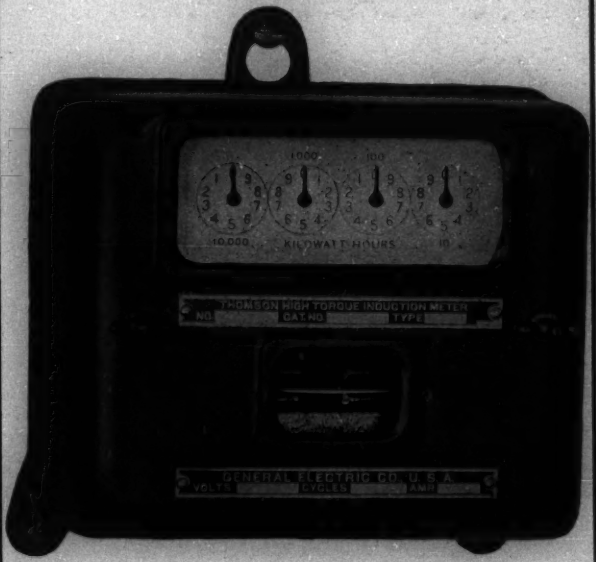

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